The GlueX experiment and its place in the global search for exotic mesons

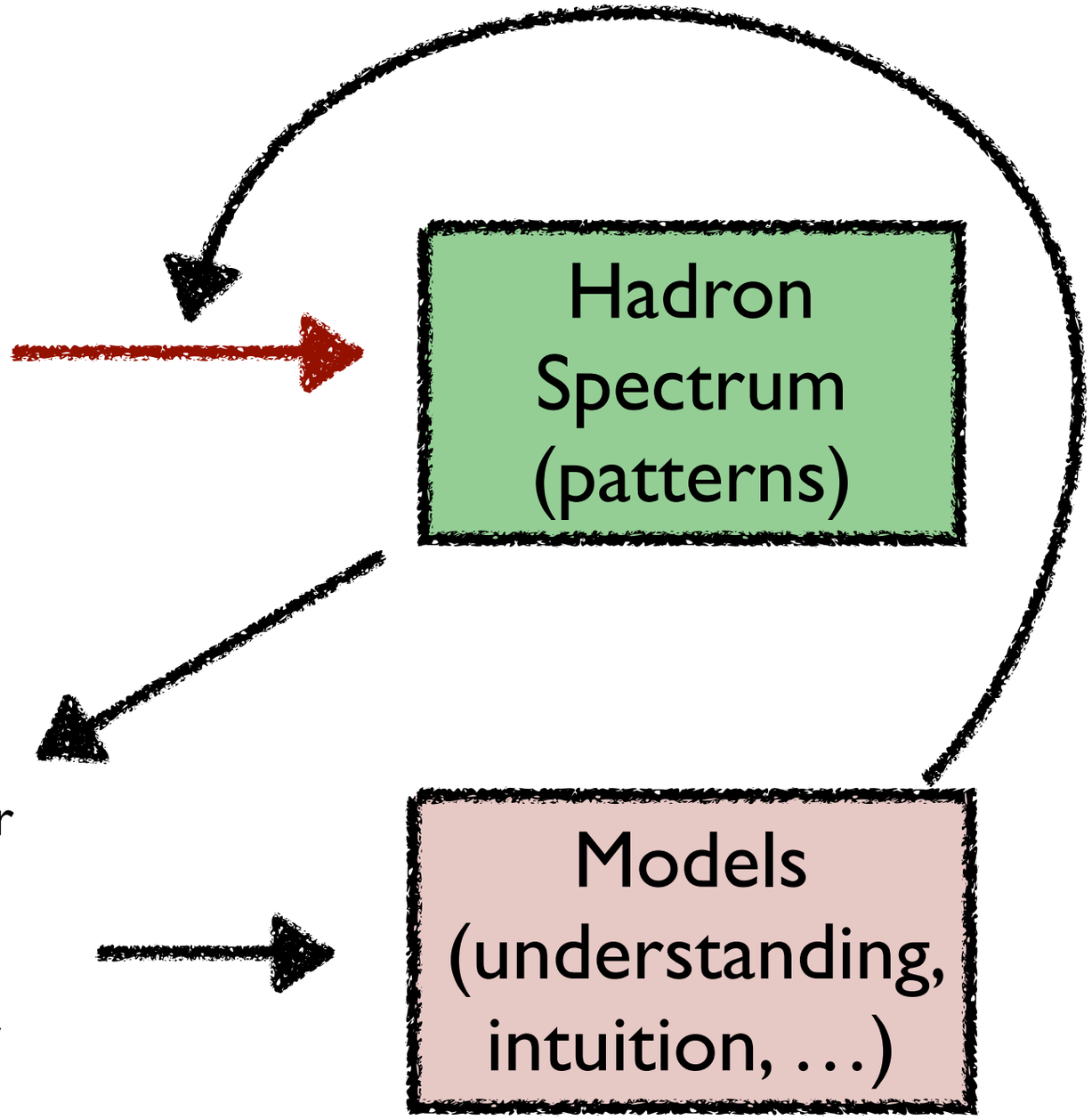
Matthew Shepherd
Indiana University

Bound States in QCD and Beyond II
St. Goar, Germany
February 21, 2017

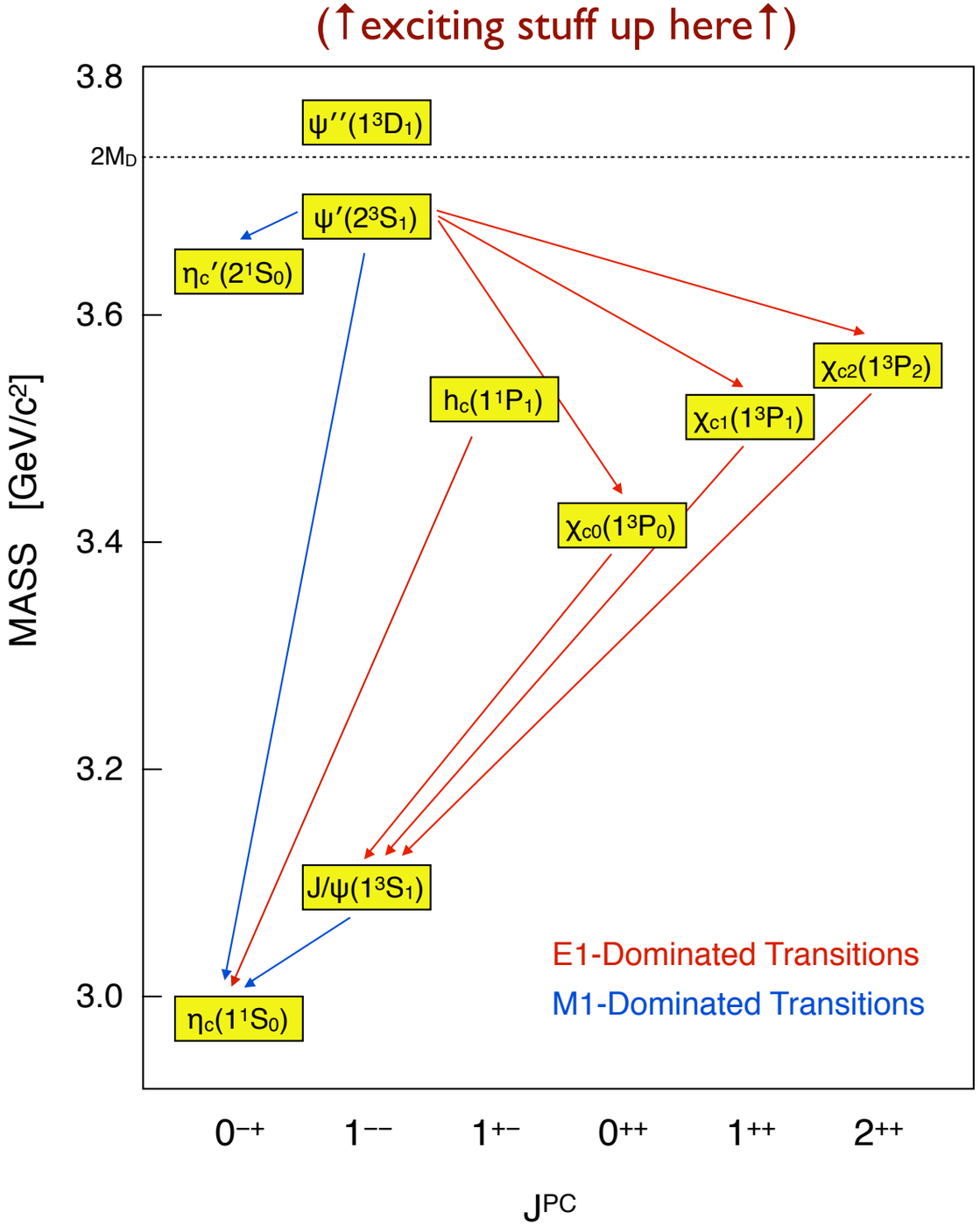
The role of hadron spectroscopy in studying QCD

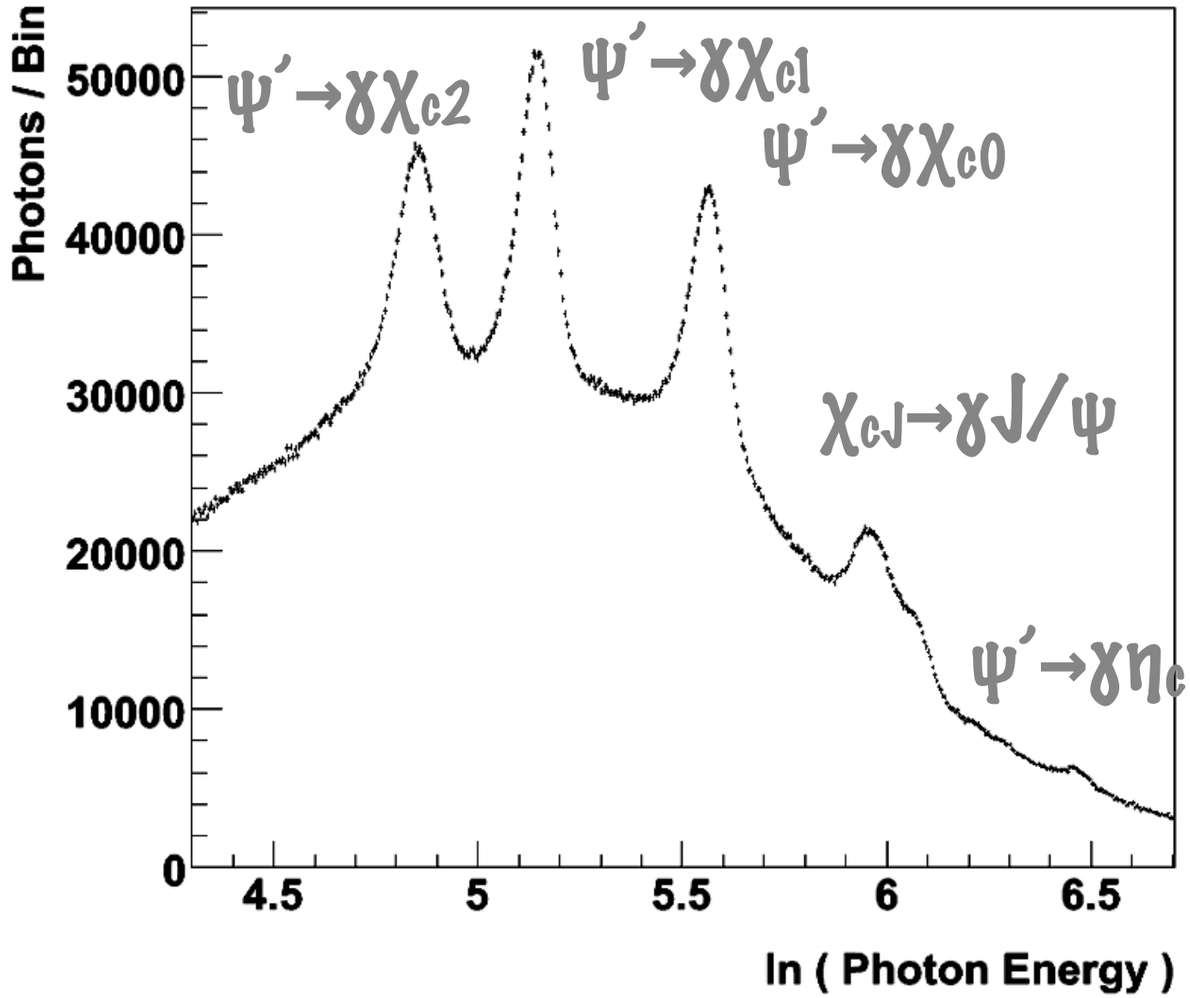
QCD and Spectroscopy

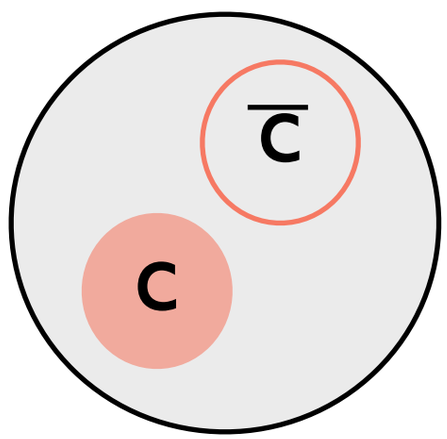
- Features of QCD
  - six flavors of quarks with various masses
  - strongly interacting quarks and gluons
  - asymptotic freedom
  - confinement
- Observations about hadrons in nature
  - spectrum dominated by colorless "quark model" states
  - gluonic degrees of freedom suppressed or difficult to observe
  - structure and spectrum of hadrons containing light quarks exhibit complexity (and simplicity)



QCD and Spectroscopy



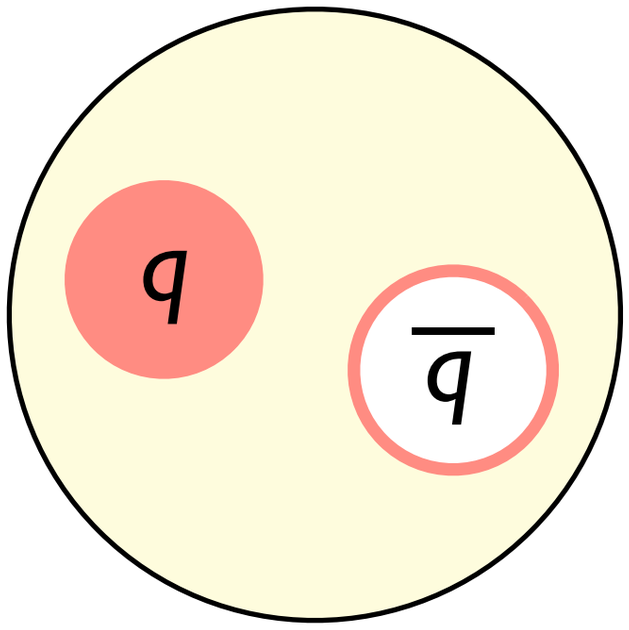




Degrees of Freedom:
a spin-1/2 fermion +
spin-1/2 anti-fermion,
each with mass of 1.5 GeV

Meson Quantum Numbers

color singlet
quark anti-quark

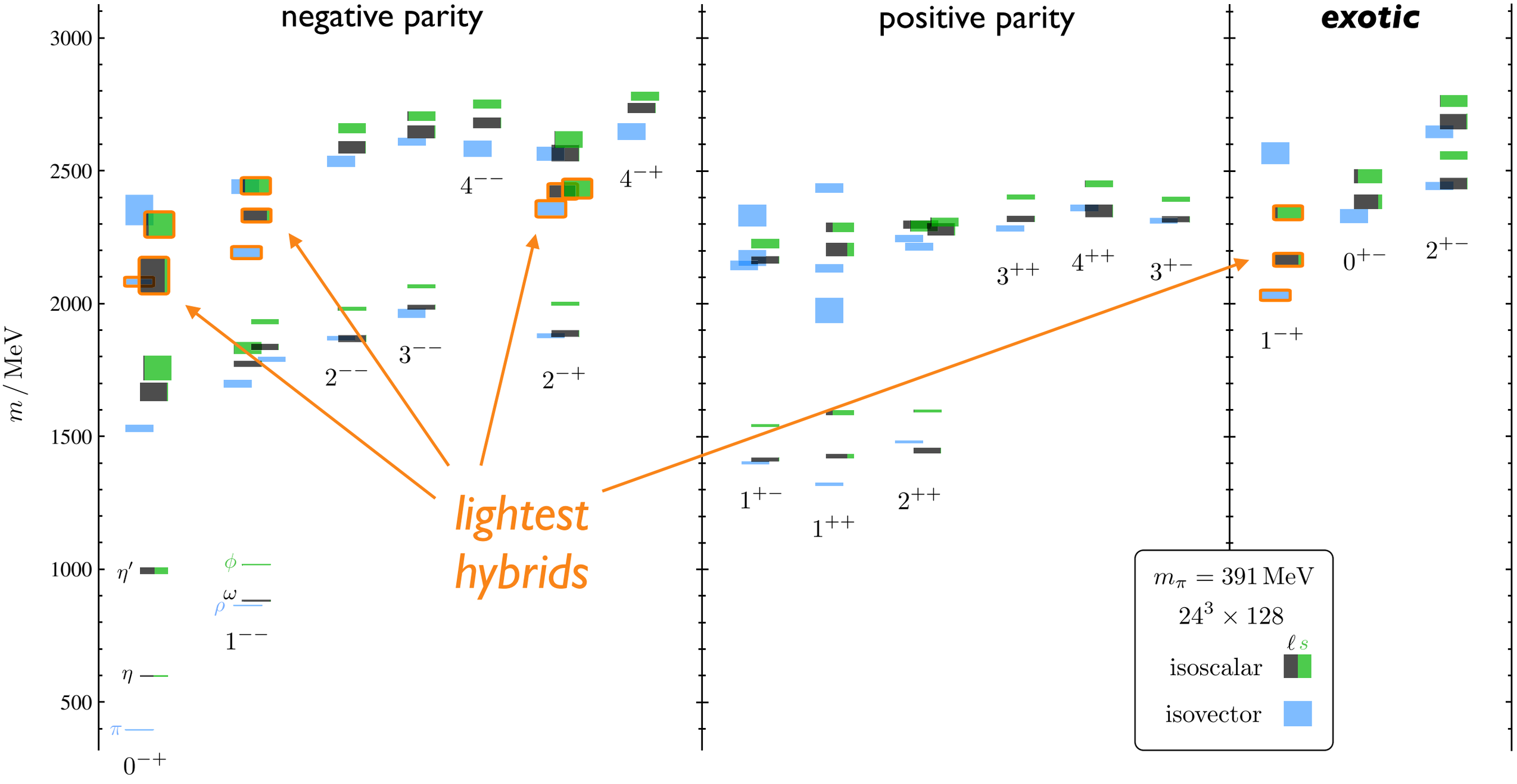


$J = L + S \quad P = (-1)^{L+1} \quad C = (-1)^{L+S}$

Allowed J^{PC}: $0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, \ldots$
Forbidden J^{PC}: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

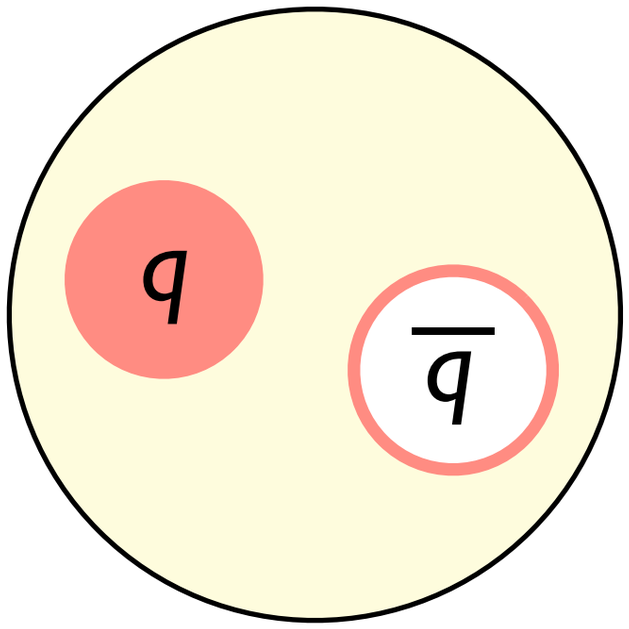
Light Quark Mesons from Lattice QCD

Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)



A Model for Hybrids

color singlet
quark anti-quark

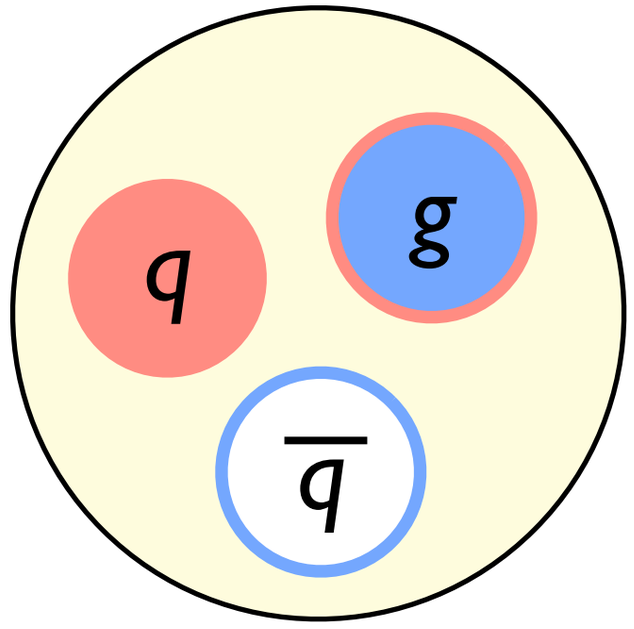


$J = L + S \quad P = (-1)^{L+1} \quad C = (-1)^{L+S}$

Allowed J^{PC}: $0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 2^{++}, \ldots$
Forbidden J^{PC}: $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

gluonic component:
$(J^{PC})_g = 1^{+-}$
mass ≈ 1.0-1.5 GeV

color-octet
$q\overline{q}$ pair



Lightest Hybrids

	$S_{q\overline{q}} = 1$	$S_{q\overline{q}} = 0$
J^{PC}:	0^{-+}, 1^{-+}, 2^{-+}	1^{--}

"exotic hybrid"

Hybrids, Tetraquarks, and Pentaquarks (…oh my)

- QCD seems to permit a particle zoo — nature prefers just a few species.
  - if true, why?
- An interesting history of hybrid searches
  - reports: VES, E852, Crystal Barrel, COMPASS, …
  - no clear spectrum of states
  - *GlueX is unique: intensity and production mechanism*
- An interesting contemporary landscape
  - strong evidence for new types of mesons in heavy quark systems
  - clear tetraquark and pentaquark candidates; perhaps hybrids with conventional quantum numbers
  - *GlueX is complementary: exploration of light quarks*

The context for the GlueX Experiment

Spectroscopy: Everybody's Doin' It

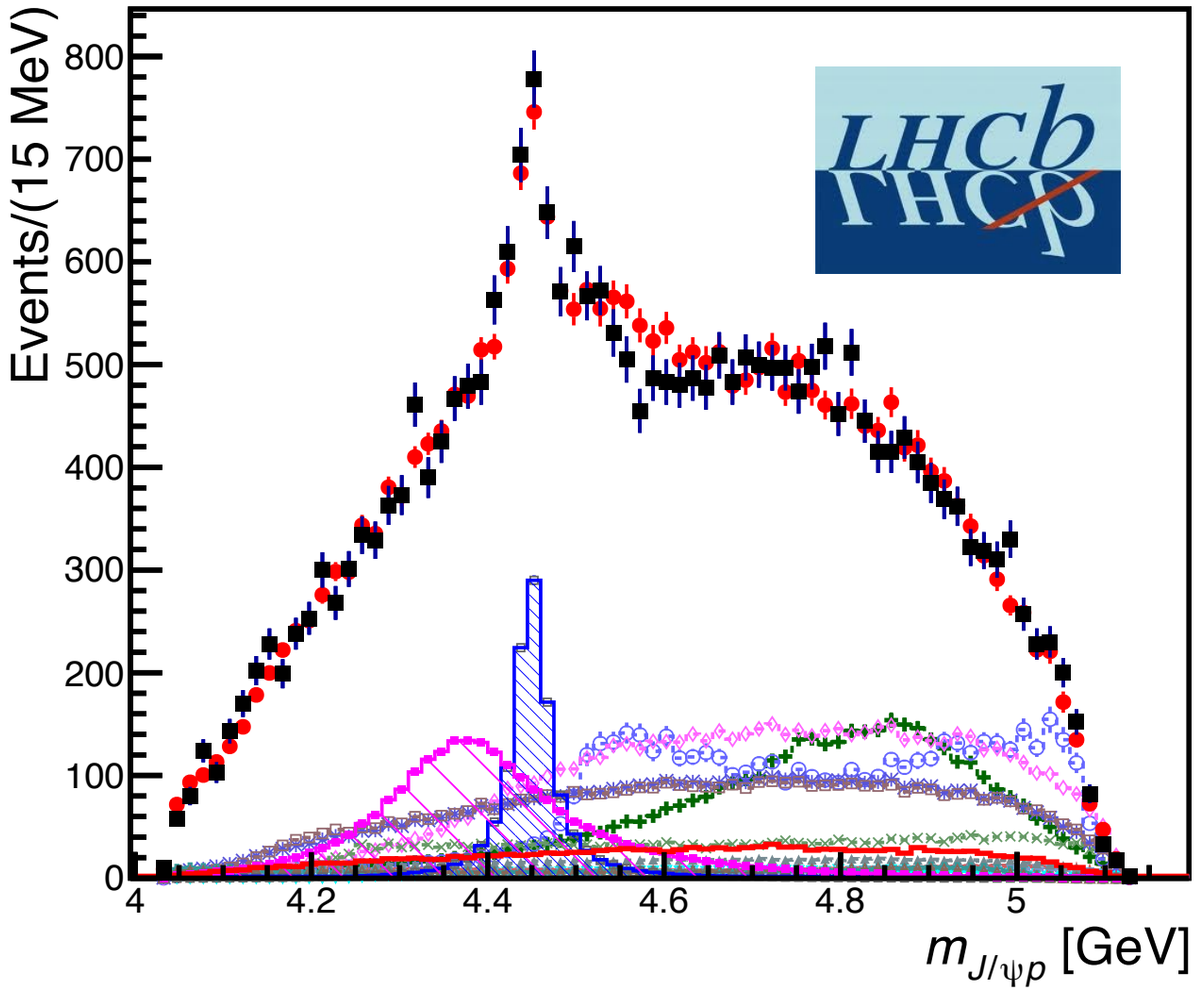
	hadron probes	electromagnetic probes
colliding beam	completed/analysis: CDF II, DØ ongoing/future: ATLAS, CMS, LHCb	ongoing/future: BESIII, Belle II completed/analysis: BaBar, Belle
fixed target	completed/analysis: COMPASS ongoing/future: PANDA	ongoing/future: GlueX, CLAS12 completed/analysis: CLAS (CEBAF Large Acceptance Spectrometer)

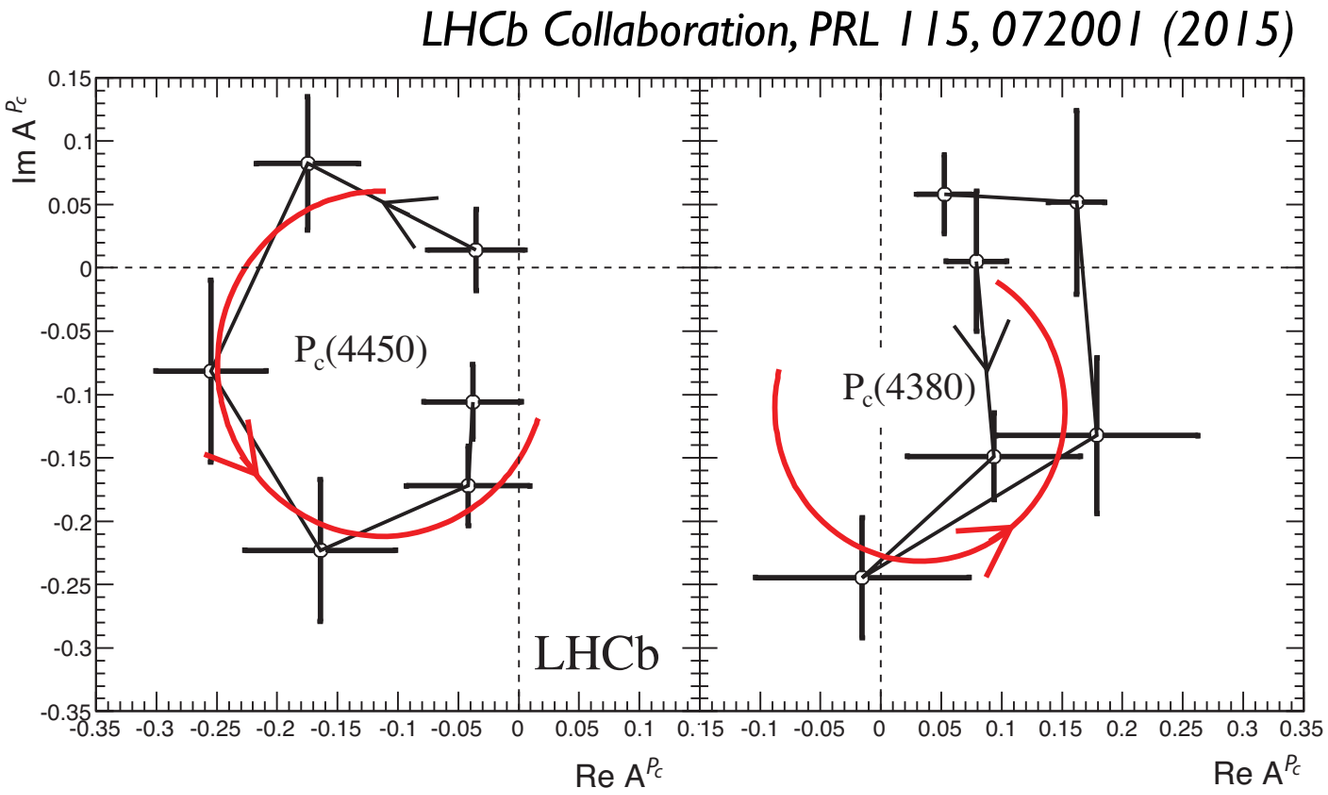
Global Context

- Exciting results in the heavy quark sector:
  - pentaquark candidates
  - tetraquark candidates
- Exciting results in the light quark sector:
  - potential exotic hybrid mesons
- An overarching theme:
  - need to confront state of the art experimental results with state of the art experimental interpretation
  - limited by the systematic uncertainties in our understanding of the underlying physics rather than our understanding of the detector or the statistical precision of the data

Baryon Spectroscopy with Charmonium

$$B \to pKJ/\psi$$





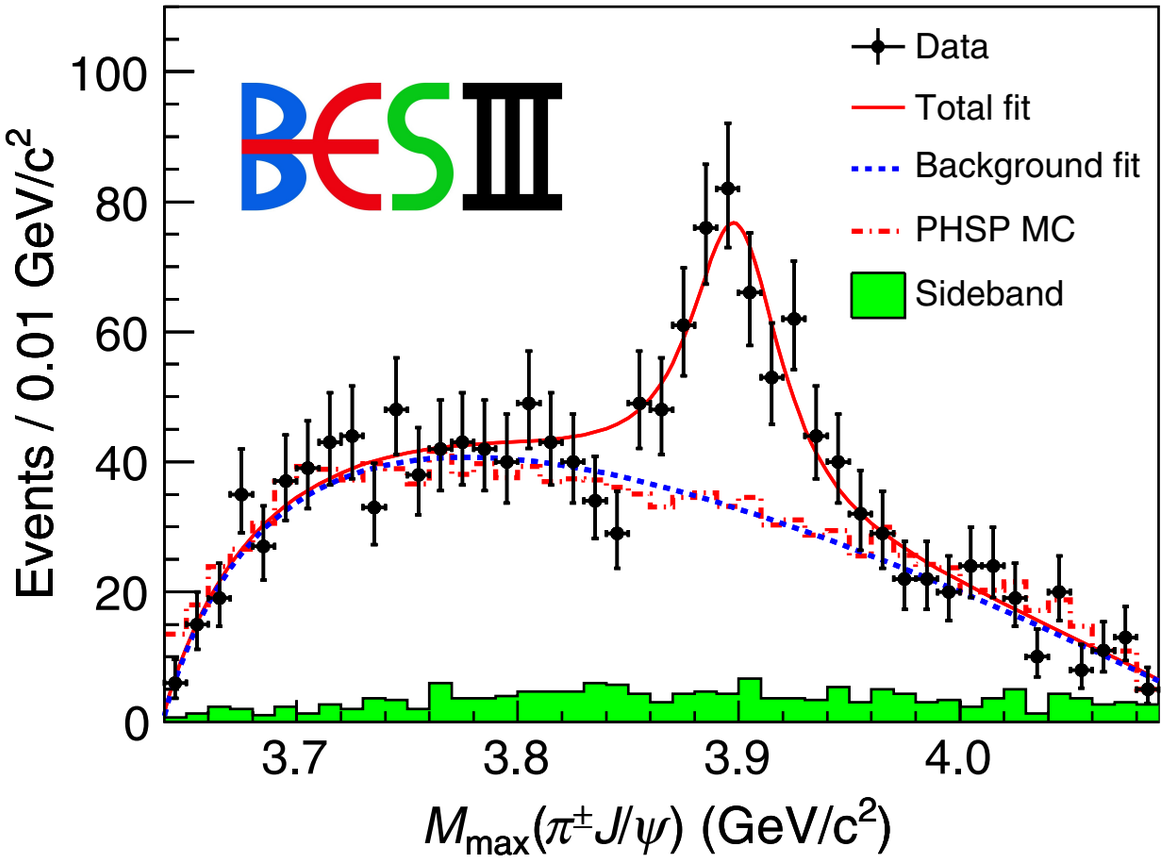
Pentaquark Candidates

Meson Spectroscopy with Charmonium

$$e^+e^- \to \pi^\mp Z_c^\pm$$

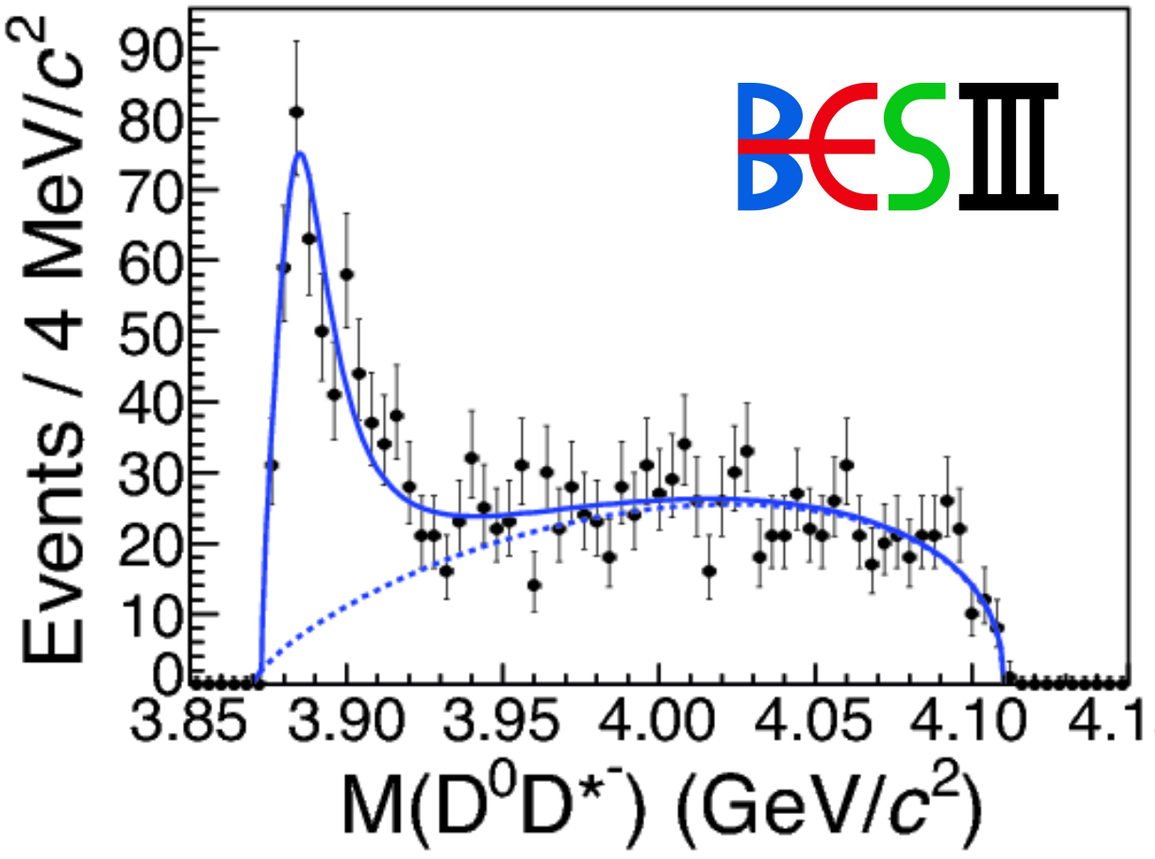
$$Z_c^\pm \to \pi^\pm J/\psi$$

BESIII Collaboration, PRL 110, 252001 (2013)



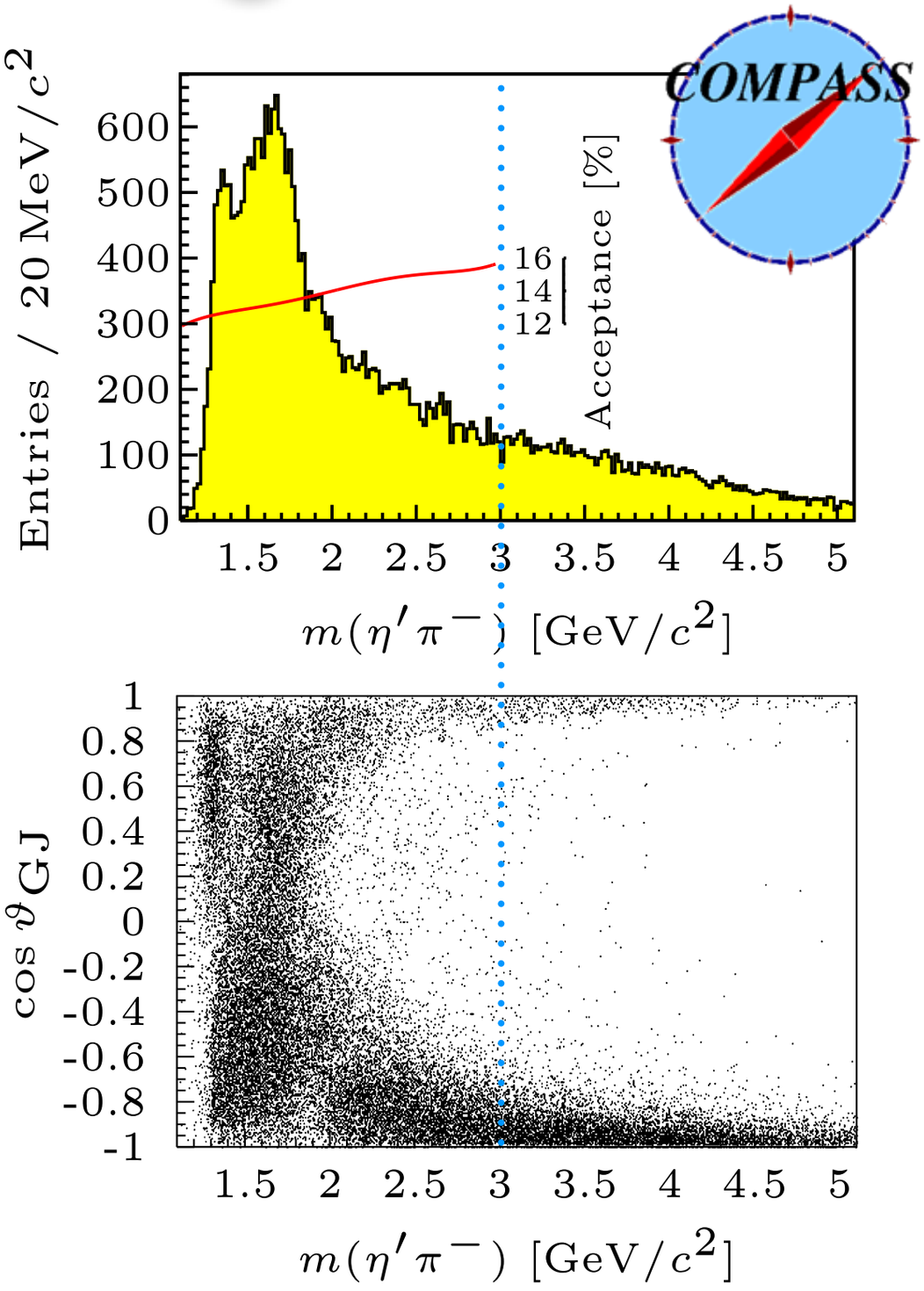
$$Z_c^\pm \to (\overline{D^0} D^*)^\pm$$

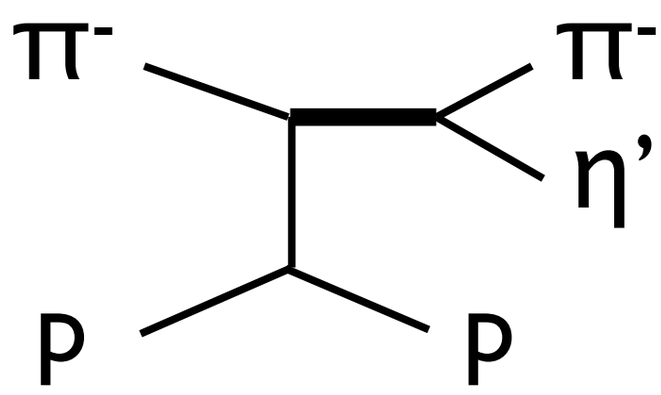
BESIII Collaboration, PRL 112, 022001 (2013)

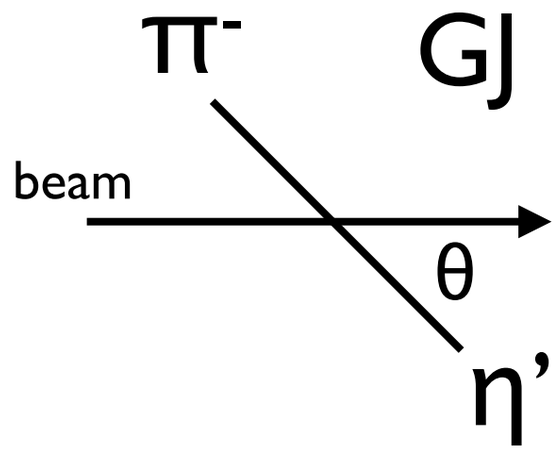


Tetraquark Candidates

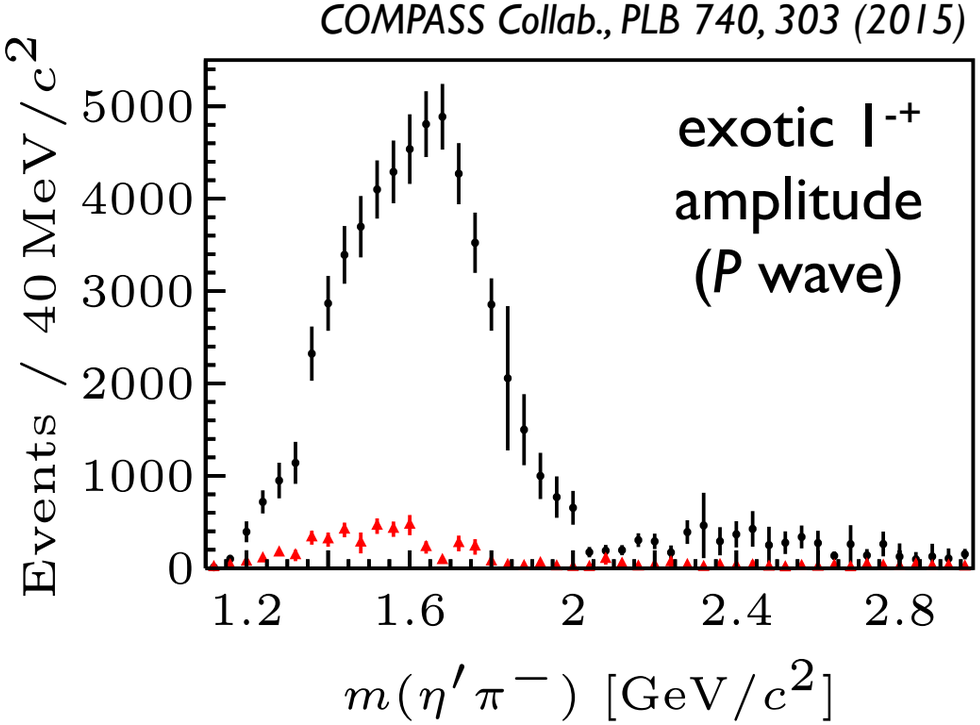
Light Mesons in Pion Production



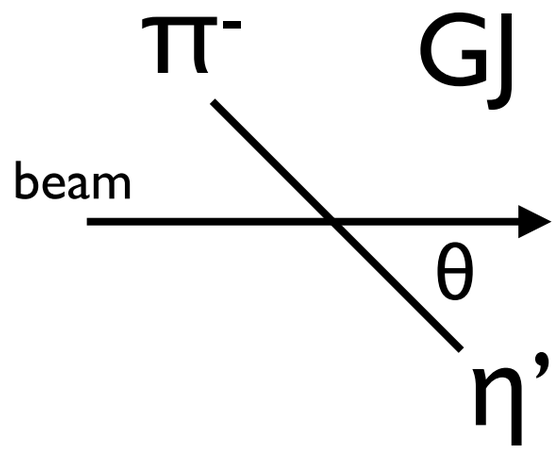




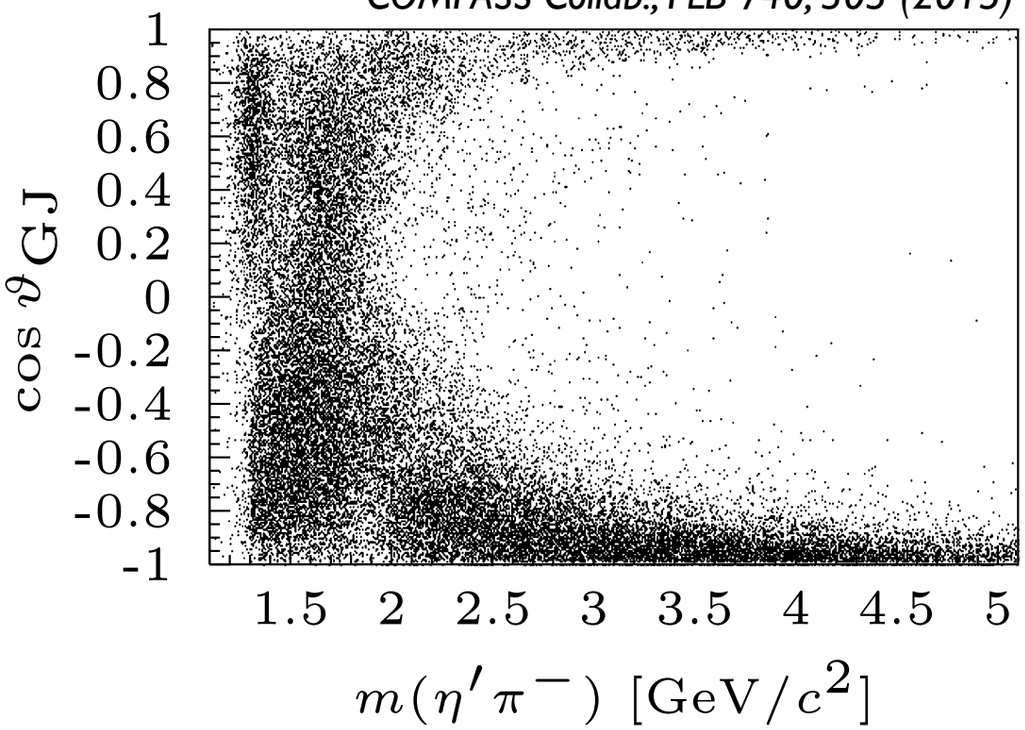
COMPASS Collab., PLB 740, 303 (2015)



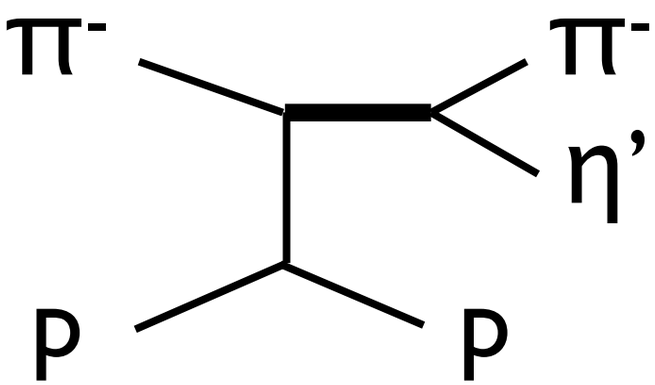
Scattering Phenomenology



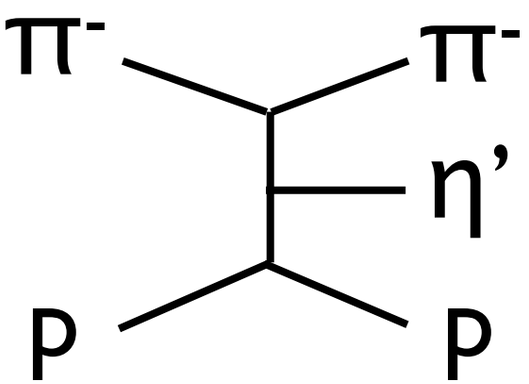
COMPASS Collab., PLB 740, 303 (2015)



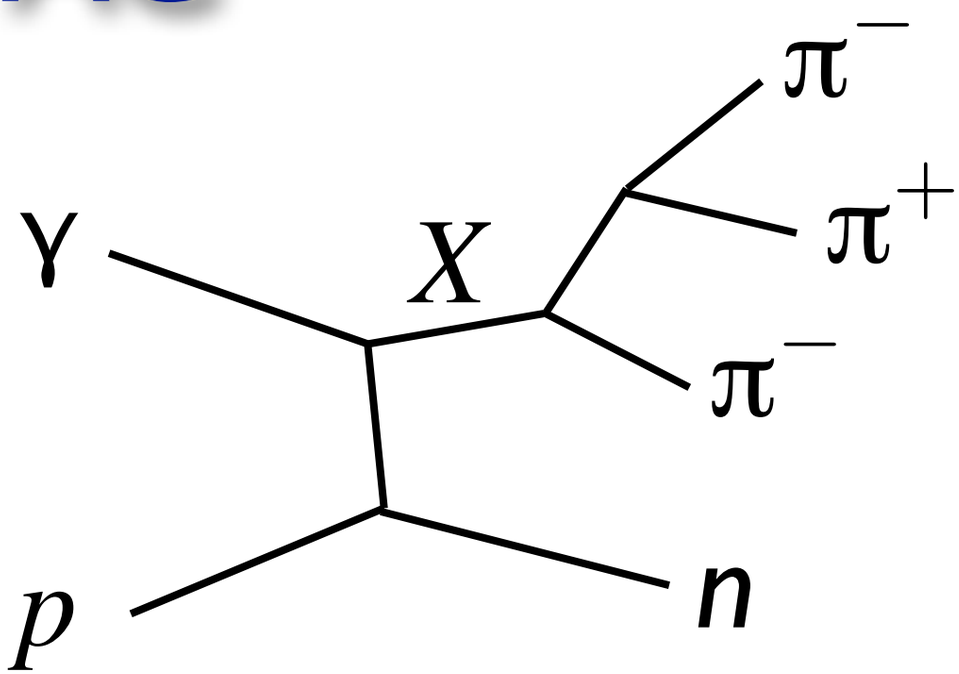
Exotic Resonance?



Not-so-exotic scattering?



GlueX + JPAC

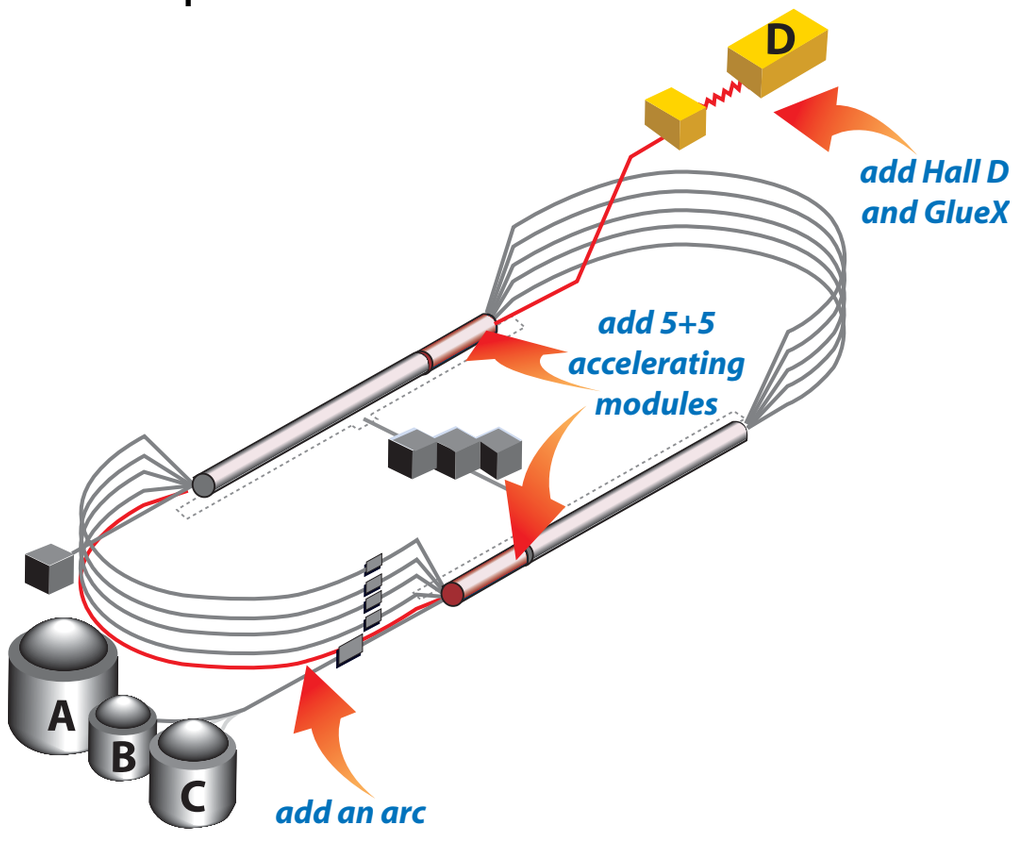


- High statistical precision allows <u>and requires</u> removing simplifying assumptions in analysis
  - more robust theoretical models ("wetware")
  - more capable analysis frameworks ("software")
- JPAC: Joint Physics Analysis Center
  - joint theory initiative led by Indiana University and Jefferson Lab
  - emphasis on phenomenology: how to interpret experimental data
  - a global network
- Direct collaboration: theorists and experimentalists working together on the analysis and interpretation of data
  - joint theory/experiment summer schools

The GlueX Experiment and its first preliminary results

GlueX in Hall D at 12 GeV JLab

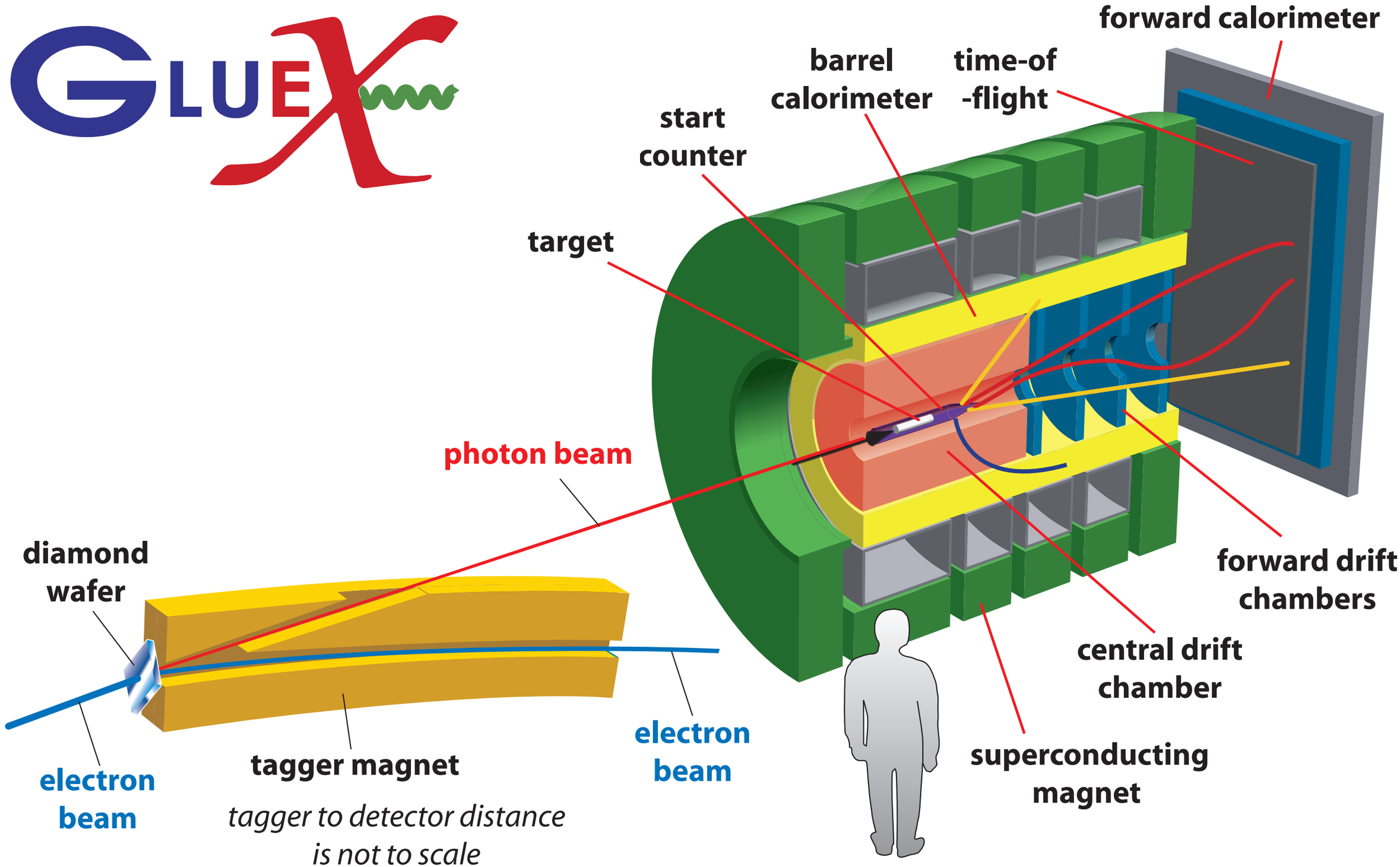
- GlueX + Hall D beamline features:
  - beam species: polarized photon; peak polarization at 9 GeV (assuming 12 GeV electron beam)
  - high intensity: 200 kHz hadronic interaction rate around 9 GeV
  - energy optimized for production of mesons with masses up to 3 GeV



GLUEX

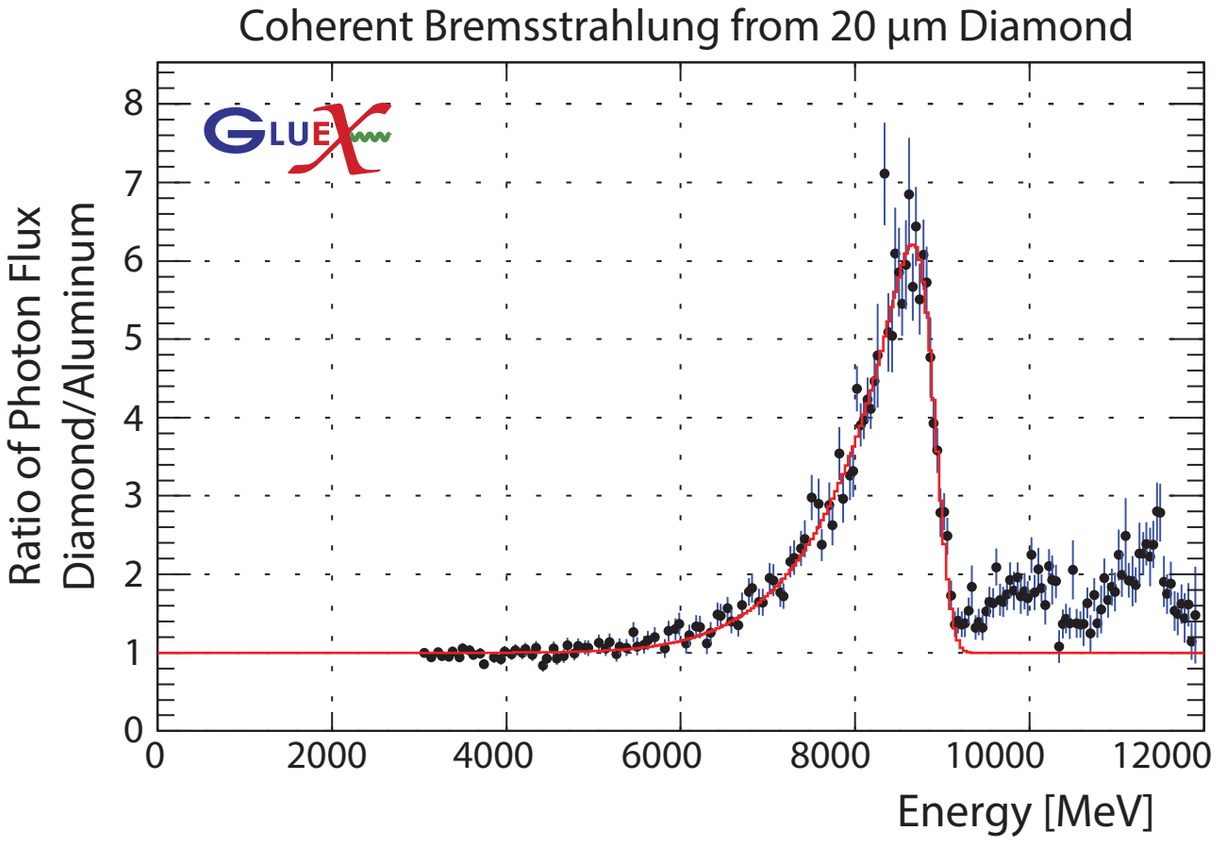
116 members from 26 institutions

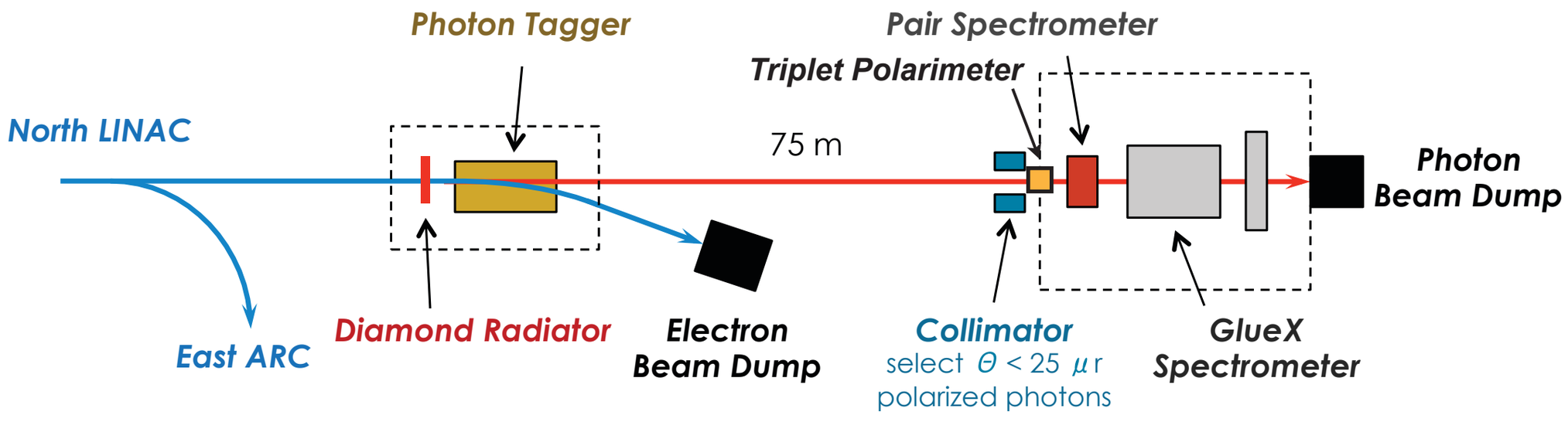
GLUEX


forward calorimeter
barrel calorimeter
time-of -flight
start counter
target
photon beam
diamond wafer
forward drift chambers
central drift chamber
superconducting magnet
electron beam
tagger magnet
electron beam
tagger to detector distance is not to scale

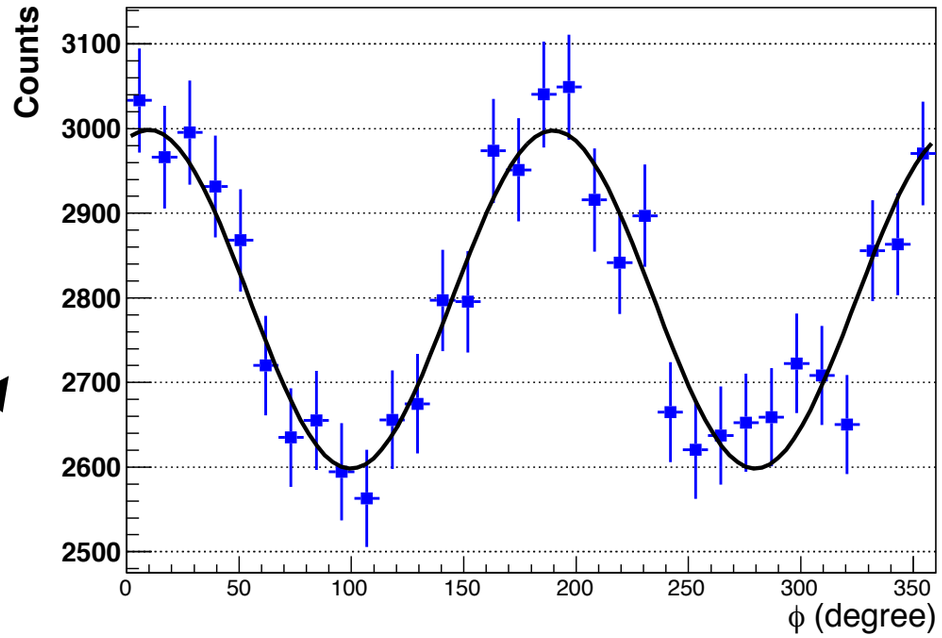
Hall D Experimental Complex
April 2012

The Hall D Photon Beamline





Flux and Polarization



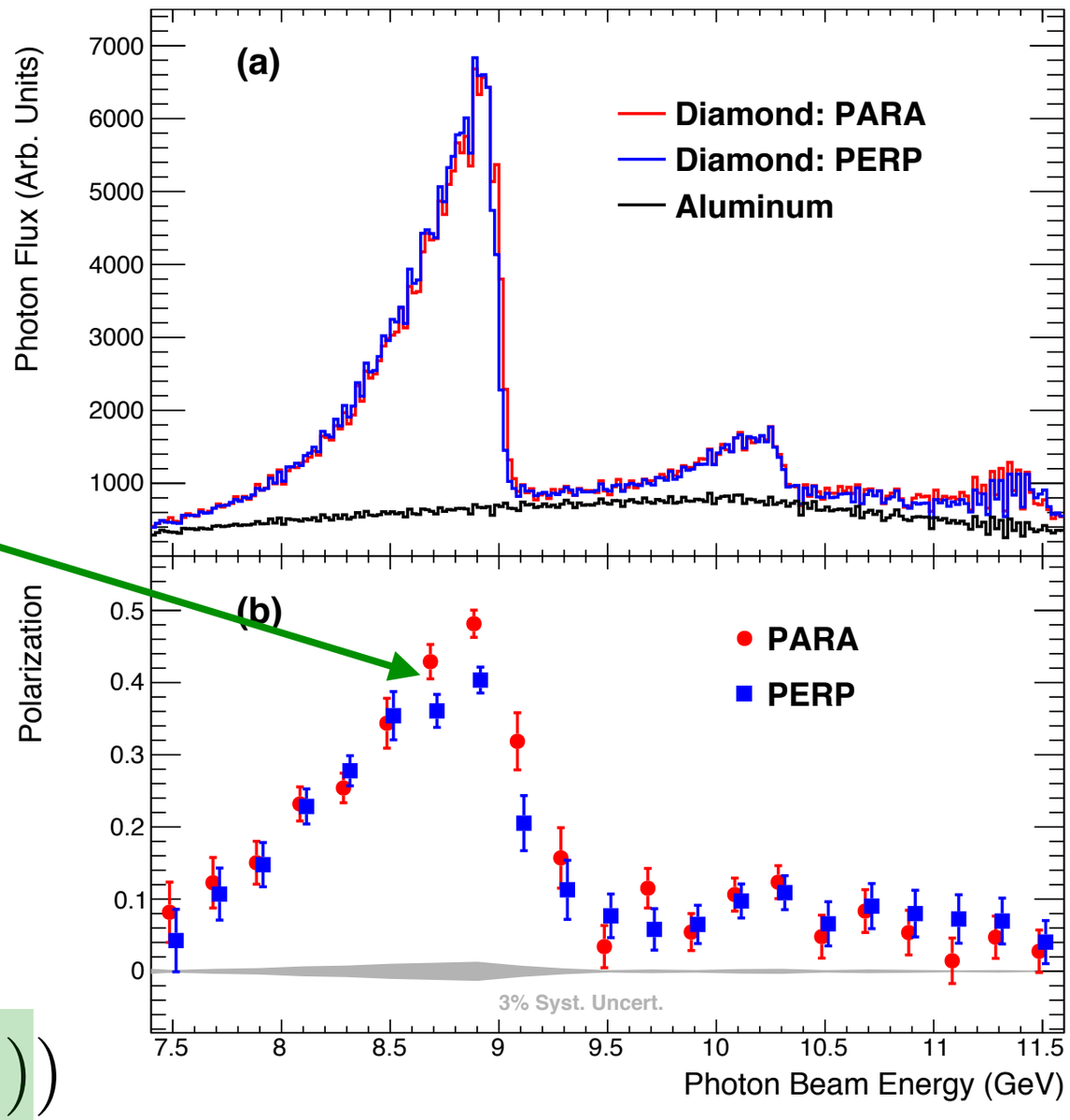
$$\gamma e^- \to e^+ e^- e^-$$

polarimeter response (simulate)

beam (measure)

QED (calculate)

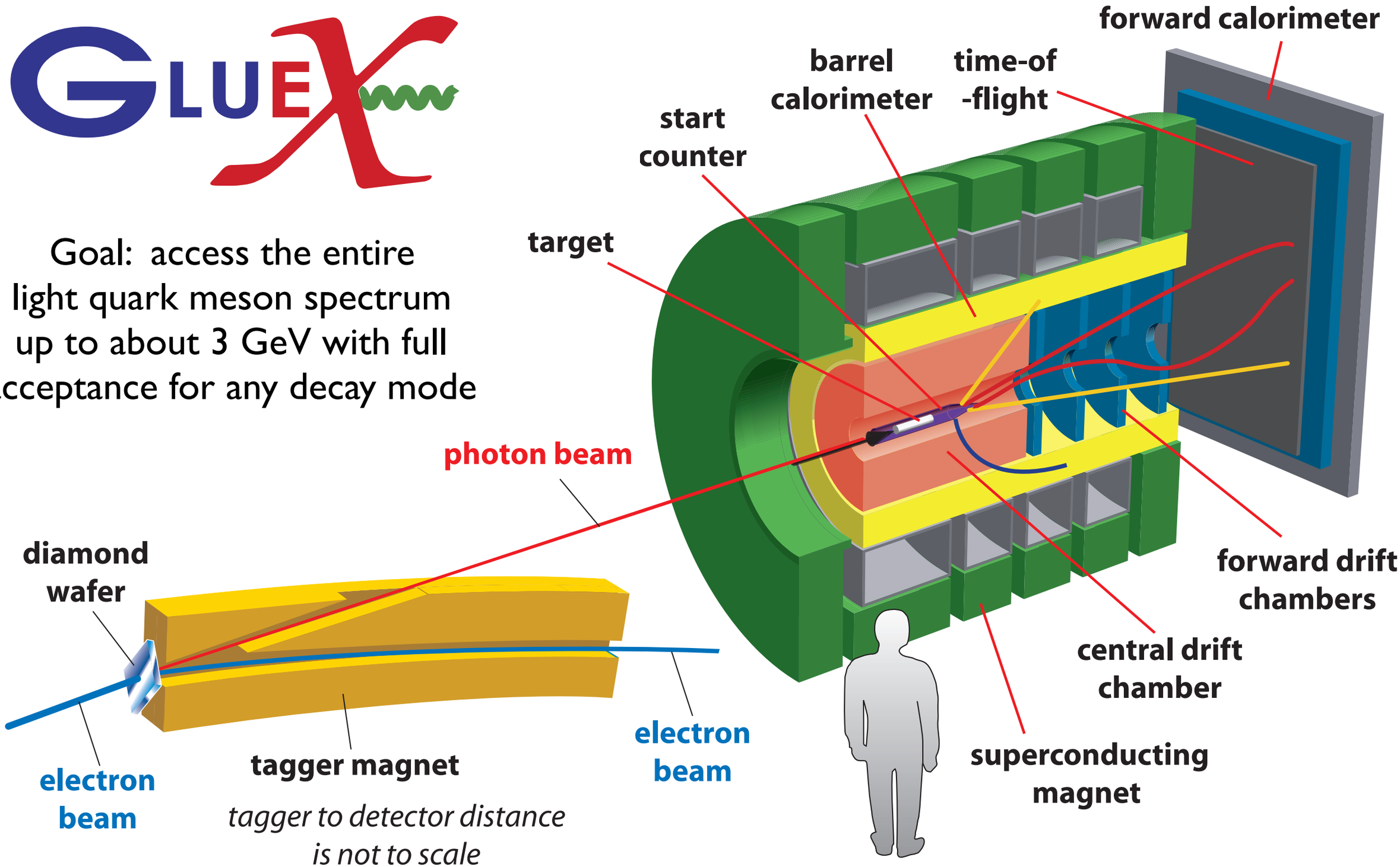
$$Y_{\parallel}(\phi) \propto A(\phi)(1 - P\Sigma\cos(2(\phi - \phi_{\gamma}^{lin}))$$



GlueX Detector with
Prof. Curtis Meyer
GlueX Spokesperson
October 2014

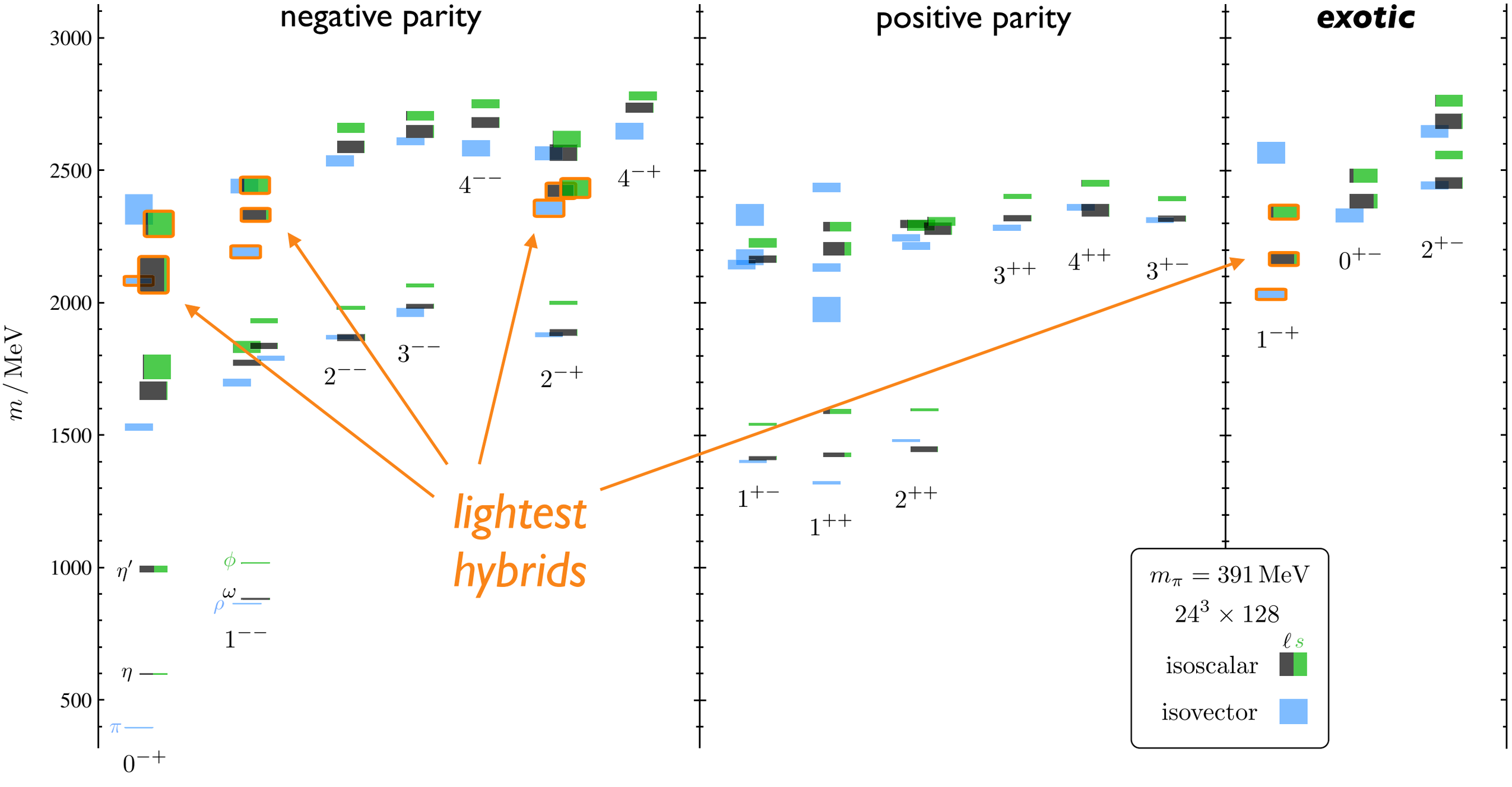
GlueX

Goal: access the entire light quark meson spectrum up to about 3 GeV with full acceptance for any decay mode

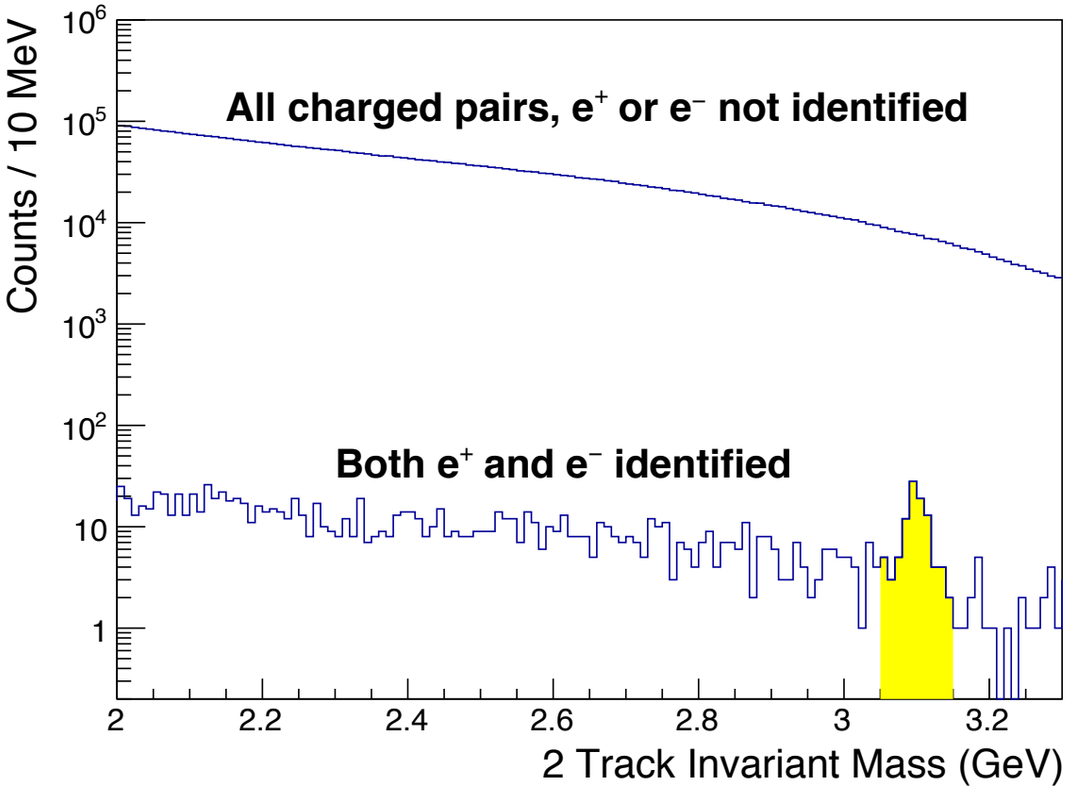


Light Quark Mesons from Lattice QCD

Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)

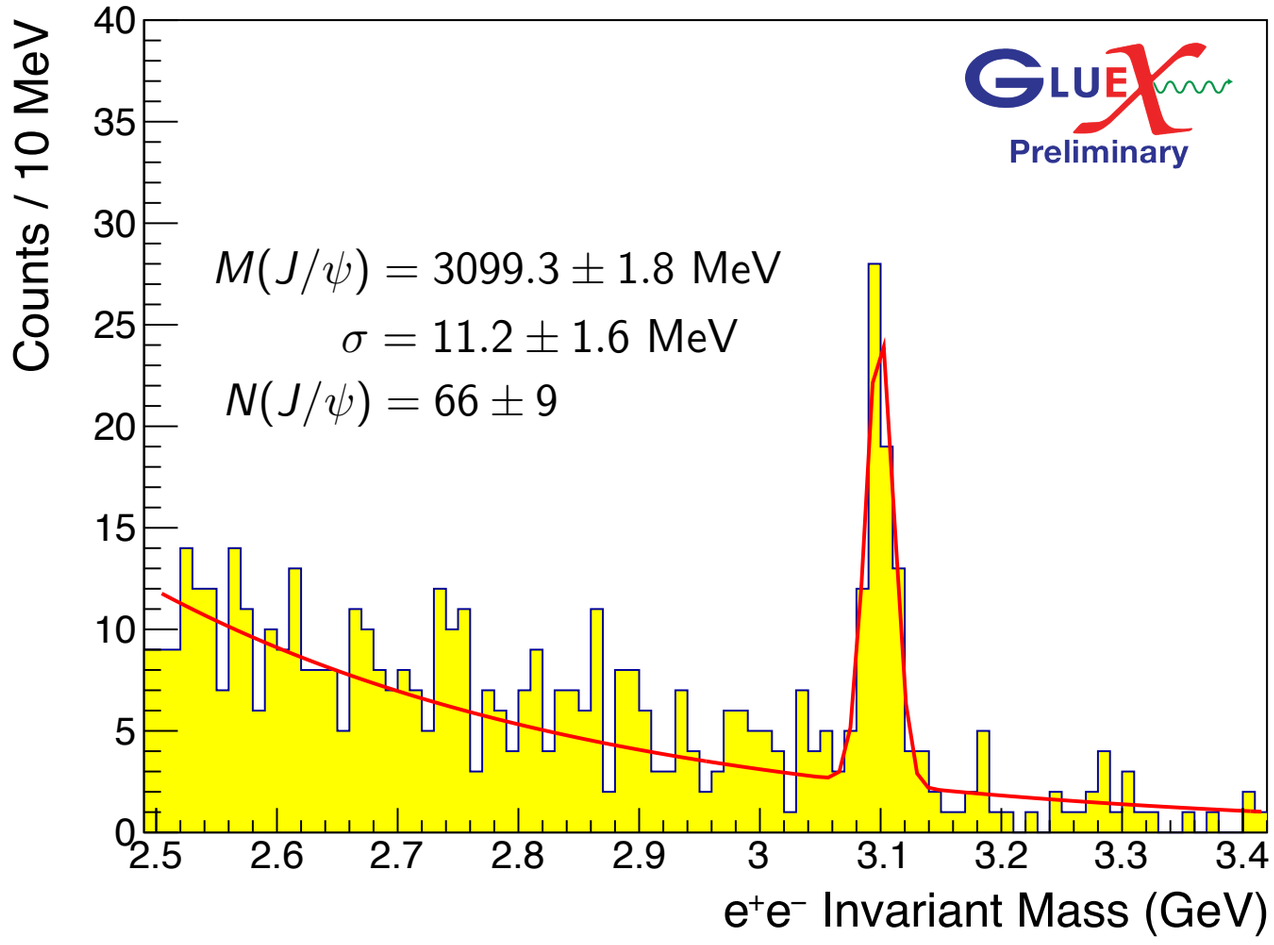


$\gamma p \rightarrow J/\psi p$; $J/\psi \rightarrow e^+e^-$



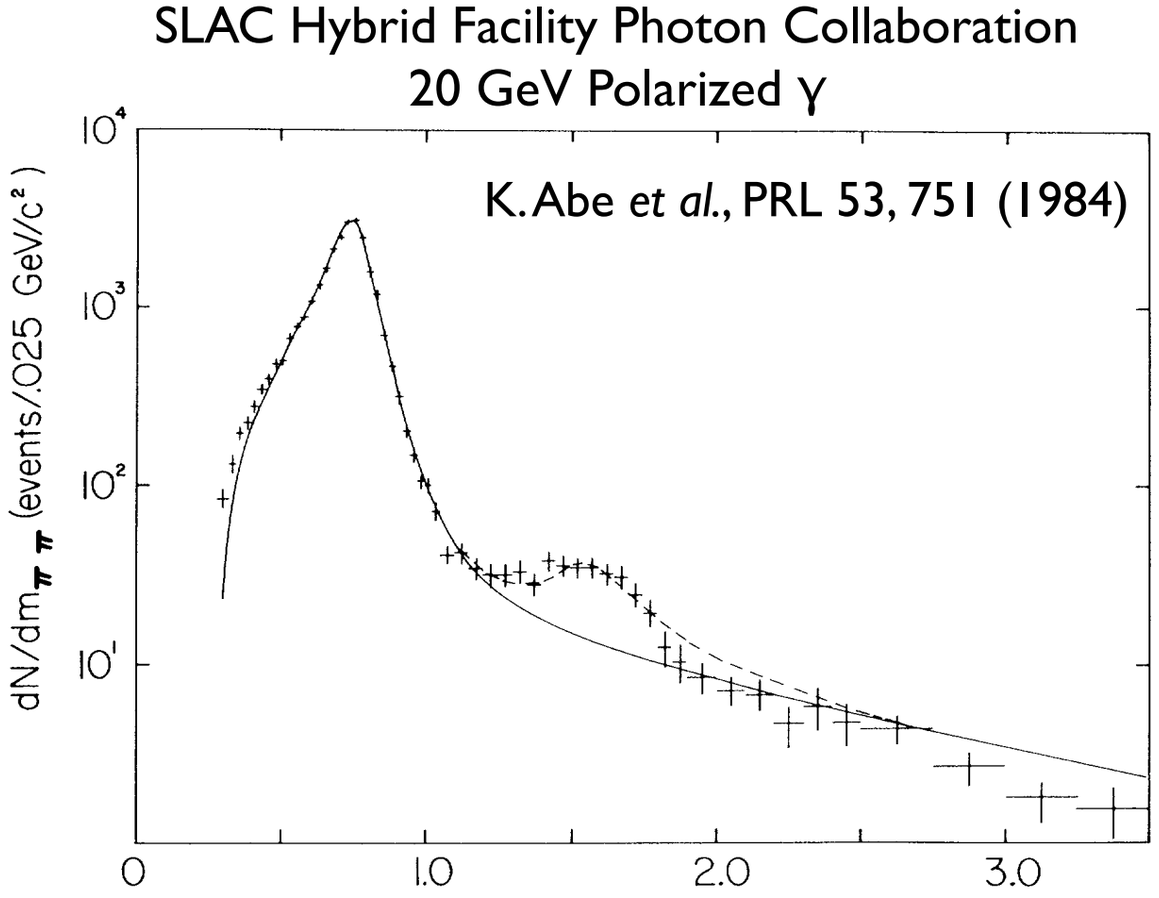
- Electron ID using *E/p* from tracking and calorimetry
- Suppression of background by four orders of magnitude

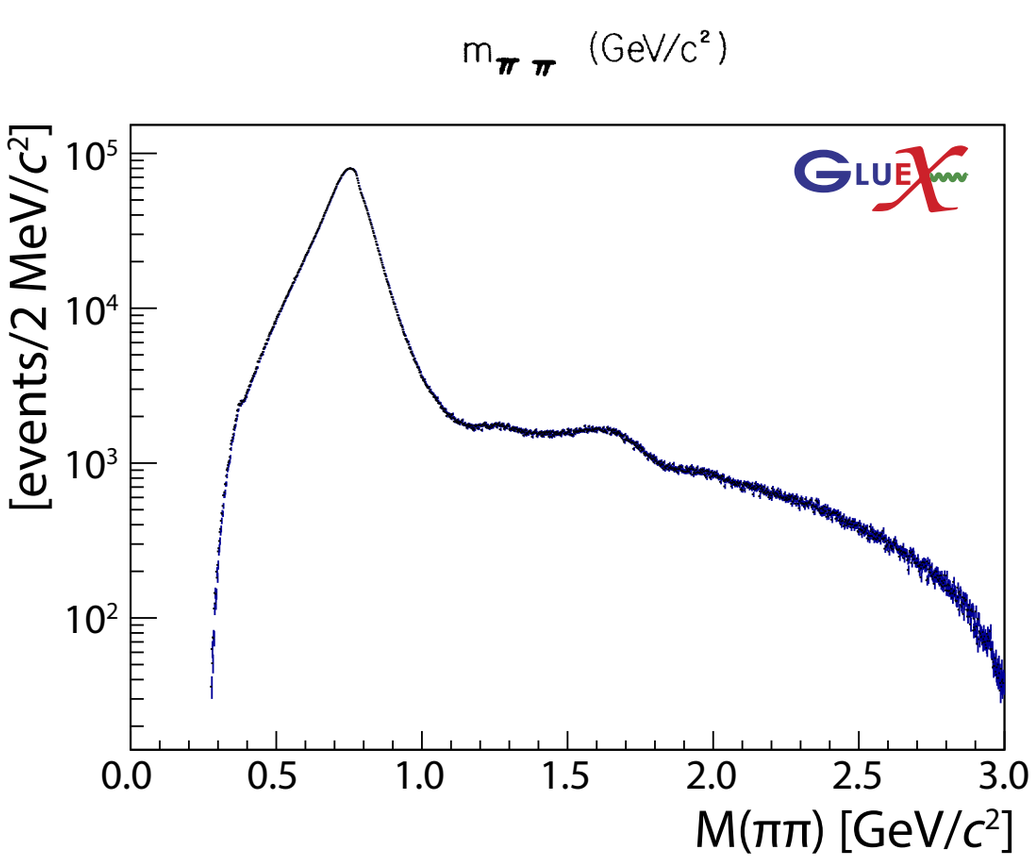
- Cross section vs. energy at threshold sensitive to production mechanism and nucleon structure
- Almost no data exist on production at threshold (E_γ = 8.2 GeV)



GlueX Intensity

- First results use a subset of spring 2016 data:
  - 82 hours beam time:
    ≈7 days at 50% efficiency
  - 10x more this year
  - 100x more in the next few years
- Typical stats:
  - 30 kHz event recording rate
  - 750 MB/s off the detector
  - 1 PB data to disk last year





Analysis Strategy

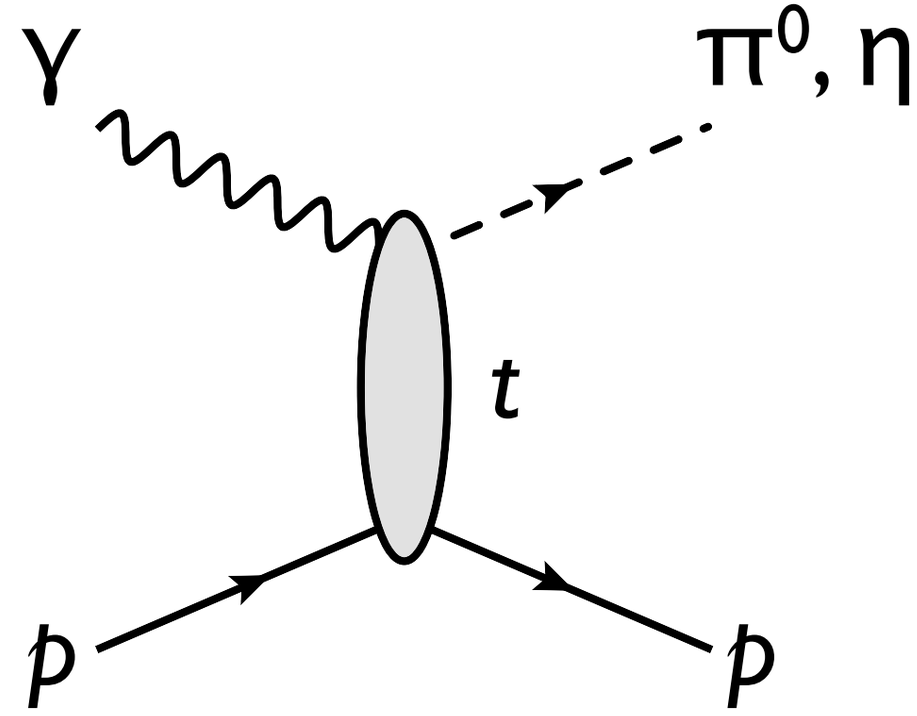
- Validate the capabilities and properties of detector with single particle production
  - benchmark cross sections
  - known branching ratios
- Initial physics results likely to be:
  - beam asymmetries
  - polarization transfer
  - bump hunting in mass spectra
  - searches for beyond standard model physics
- On the path to a core program of:
  - amplitude analysis of multi-particle final states: hybrid searches
  - precision cross section measurements

Single Pseudoscalar Production Asymmetry

- Angle between polarization plane and reaction plane is sensitive to parity of exchange

$$\sigma_{pol}(\phi, \phi_\gamma^{lin}) = \sigma_{unpol}\left[1 - P_\gamma \Sigma cos\left(2(\phi - \phi_\gamma^{lin})\right)\right]$$

- Detector systematics removed by rotating polarization plane by 90 degrees and computing asymmetry
- Asymmetry Σ has a *t* dependence
- Constrains *t*-channel backgrounds for *s*-channel baryon resonance production



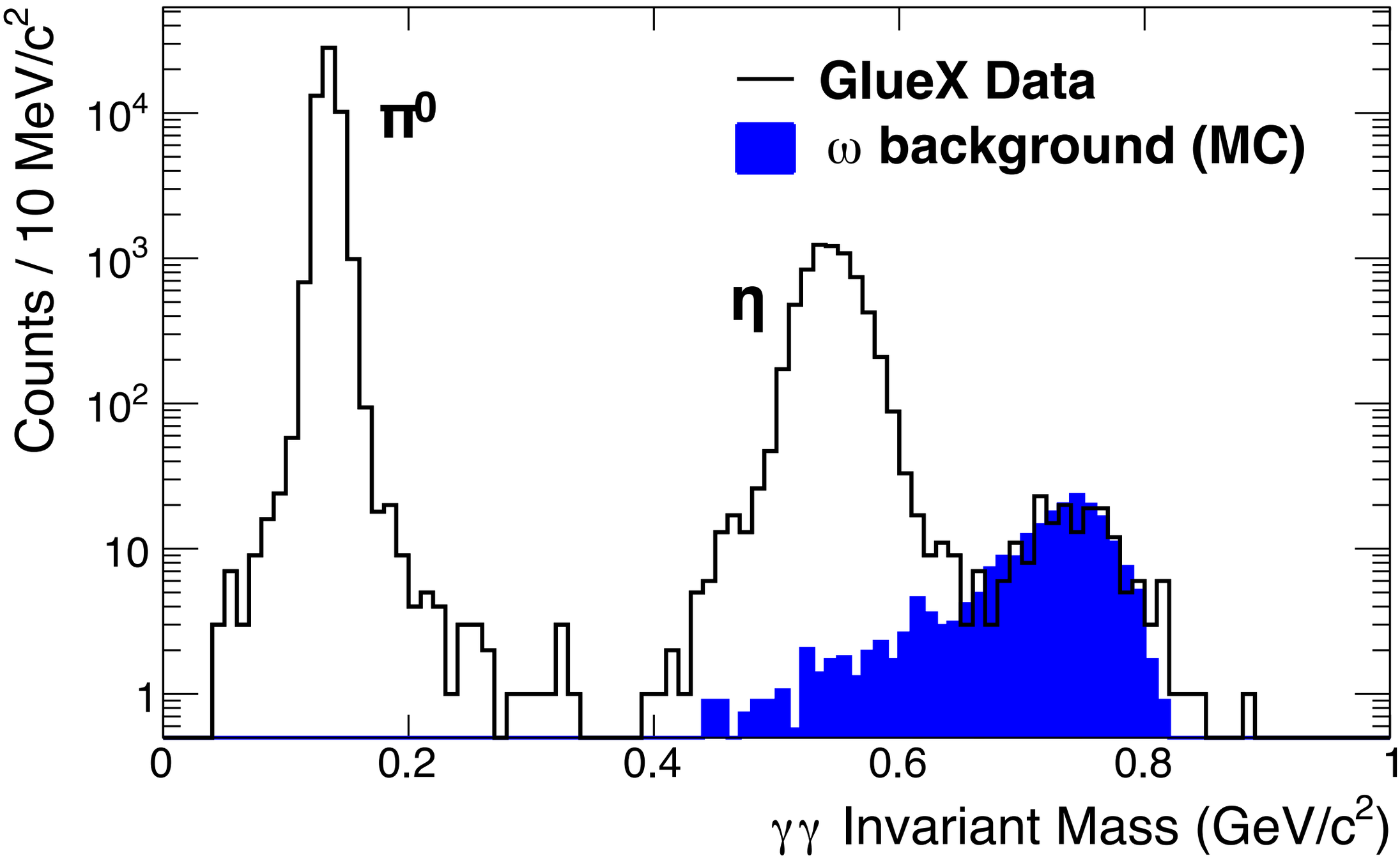
Exchange J^{PC}

$$1^{--} : \omega, \rho$$

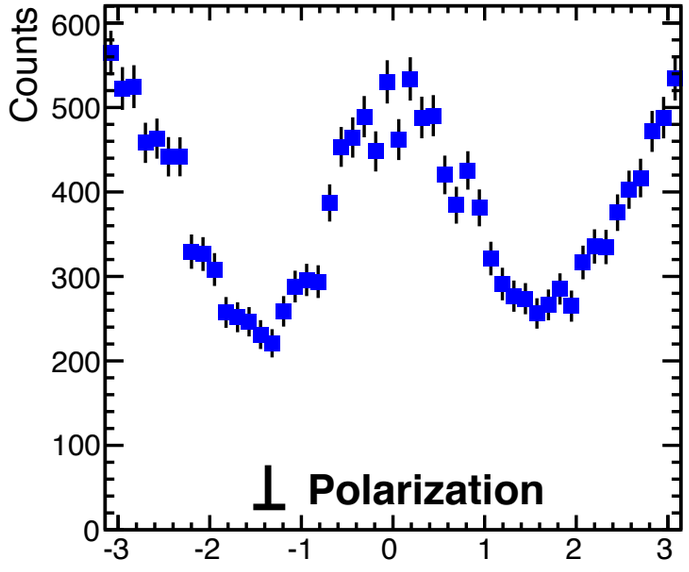
$$1^{+-} : b, h$$

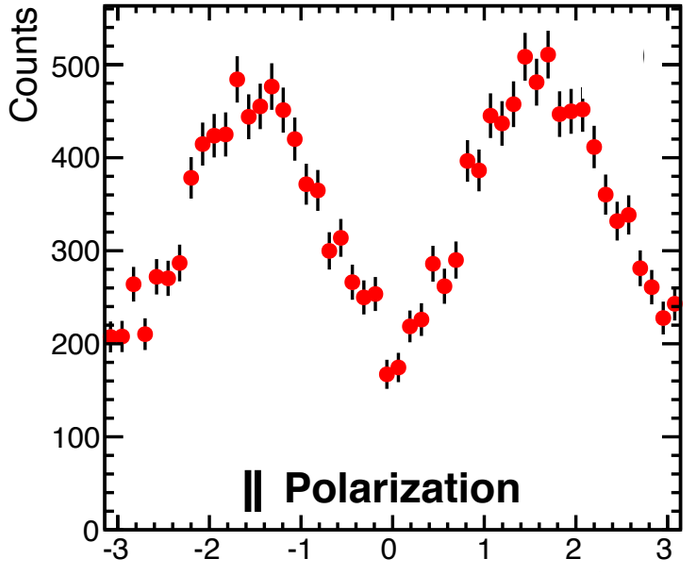
$$\Sigma = \frac{|\omega + \rho|^2 - |h + b|^2}{|\omega + \rho|^2 + |h + b|^2}$$

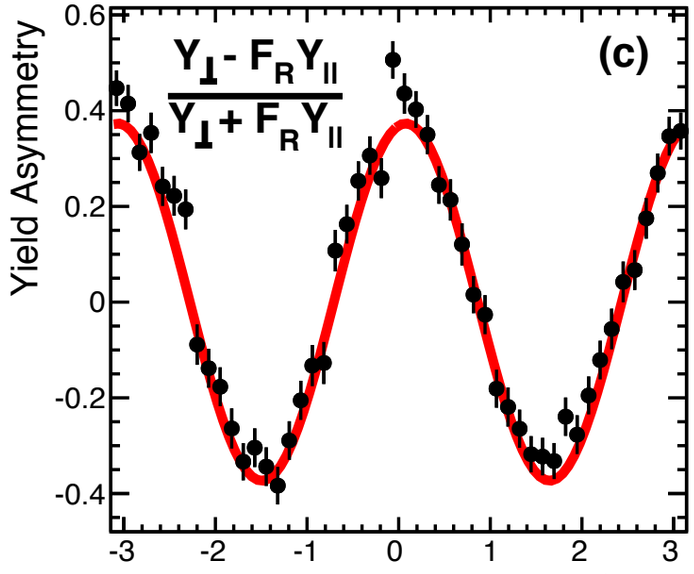
$\gamma p \rightarrow \gamma\gamma p$



Asymmetry Measurement







$$\sigma_{pol}(\phi, \phi_\gamma^{lin}) = \sigma_{unpol}\left[1 - P_\gamma \Sigma cos\left(2(\phi - \phi_\gamma^{lin})\right)\right]$$

$$F_R = \frac{N_\perp}{N_\parallel}$$

Flux **Acceptance**

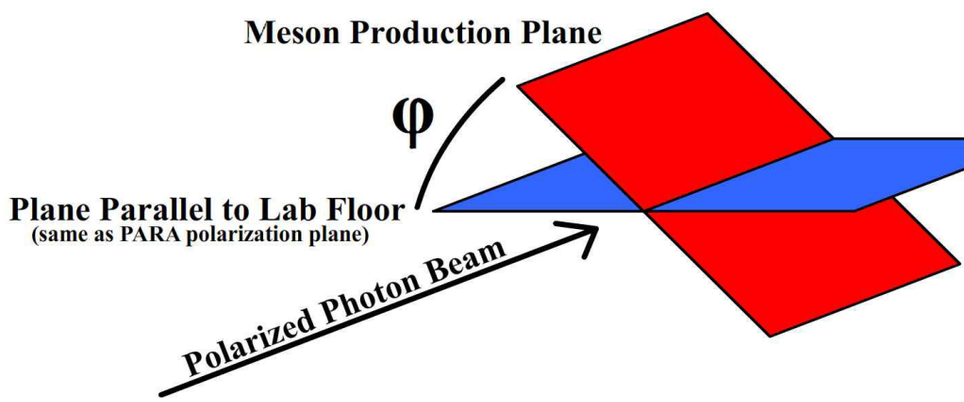
Polarized Yields

$$Y_\parallel(\phi) \sim N_\parallel A(\phi)(1 - P_\parallel \Sigma cos2\phi) \qquad \phi_\gamma^{lin} = 0°$$

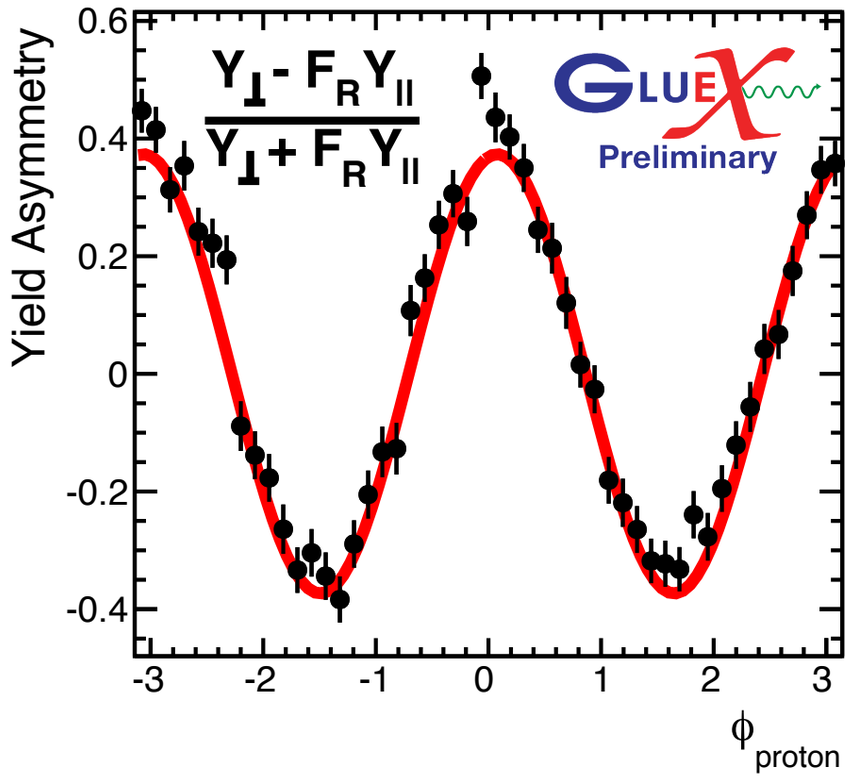
$$Y_\perp(\phi) \sim N_\perp A(\phi)(1 + P_\perp \Sigma cos2\phi) \qquad \phi_\gamma^{lin} = 90°$$

Normalized Yield Asymmetry

$$\frac{Y_\perp(\phi) - F_R Y_\parallel(\phi)}{Y_\perp(\phi) + F_R Y_\parallel(\phi)} = \frac{1 + P_\perp \Sigma cos2\phi - (1 - P_\parallel \Sigma cos2\phi)}{1 + P_\perp \Sigma cos2\phi + (1 - P_\parallel \Sigma cos2\phi)}$$



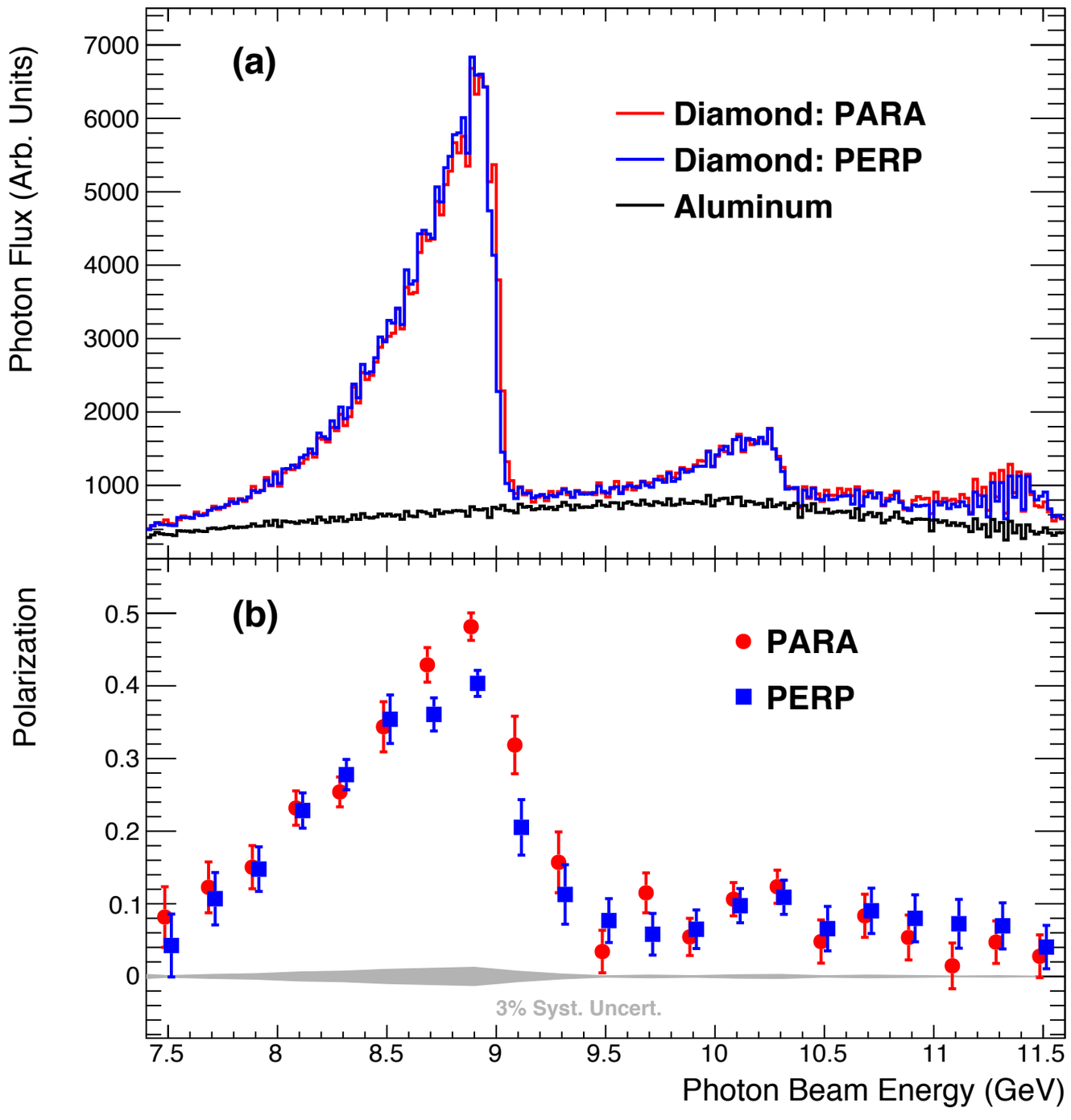
Extracting Σ



$$f(\phi) = \frac{\bar{P}\Sigma cos2\phi}{1 - \Delta P \Sigma cos2\phi}$$

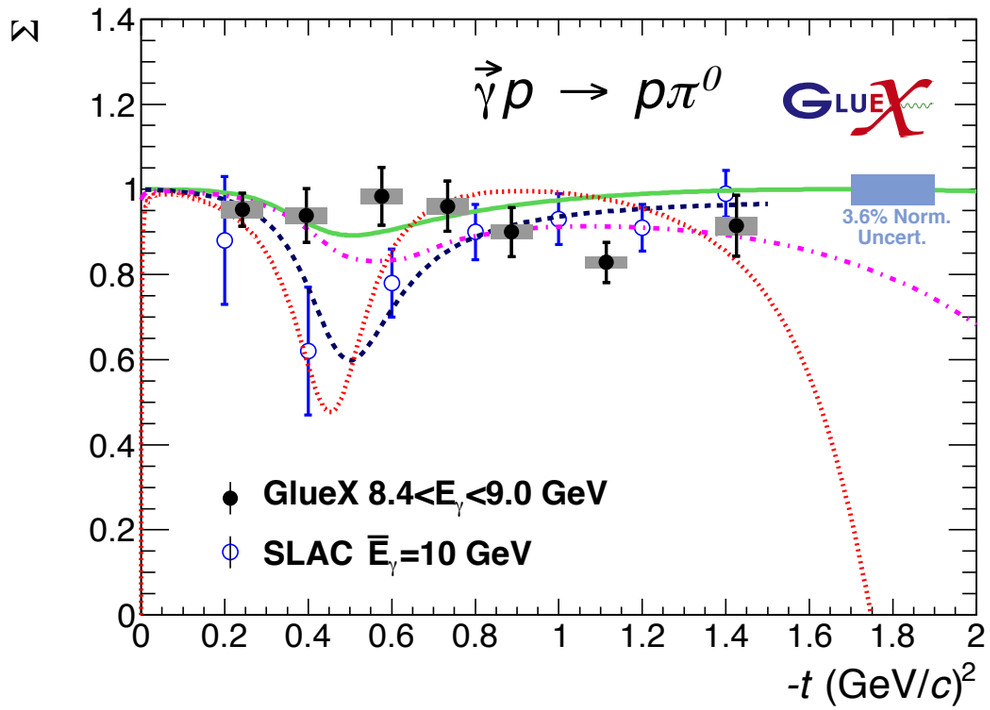
$$\bar{P} = \frac{P_\perp + P_\parallel}{2} \qquad \Delta P = \frac{P_\perp - P_\parallel}{2}$$

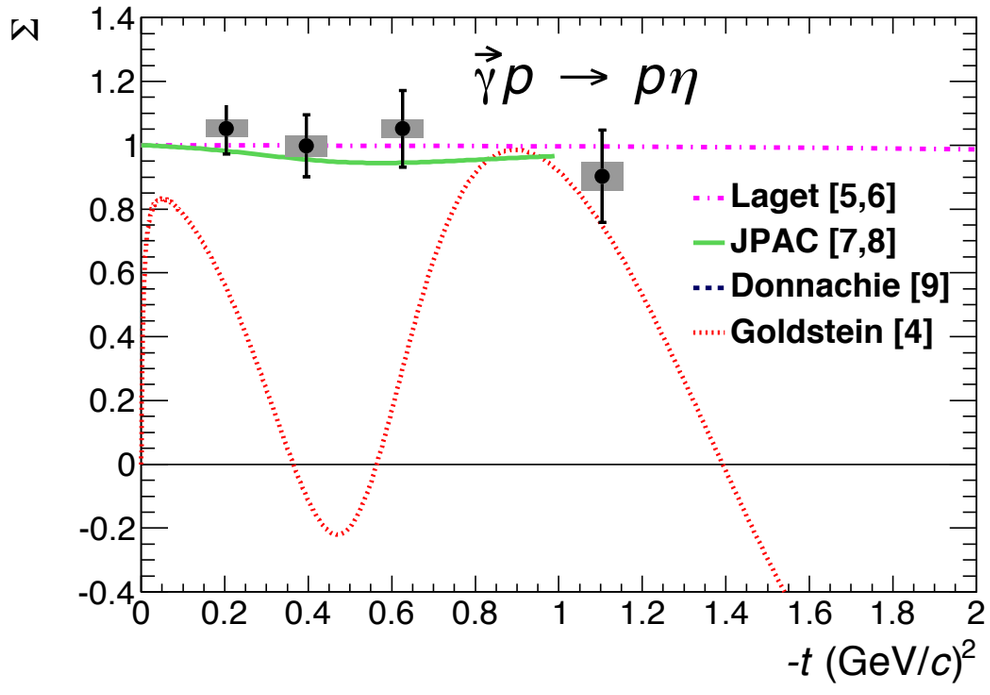
GlueX Collaboration, arXiv:1701.08123 (subm. to PRL)



Single Pseudoscalar Production Asymmetry

- Correlated uncertainty due to polarization: < 5%
- GlueX π^0 production asymmetry
  - more precise than SLAC
  - no dip around t = 0.5 (GeV/c)^2
- First measurements of η production asymmetry
- A test of high energy *t*-channel production models
- *Similar production mechanism expected for exotics*





Summary

- Use spectroscopy to understand the degrees of freedom present when hadrons are constructed in QCD
  - how are these linked to interactions in the QCD Lagrangian?
- The last ten years have been very exciting
  - candidates for hybrids, pentaquarks, tetraquarks
  - most activity in the heavy quark sector
- GlueX is well positioned to carry this momentum into the future
  - unique opportunity to study of the light quark spectrum in photoproduction
  - data are being collected and a program of analysis has begun
  - first results submitted for publication